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Final Technical Report

Validation and Implementation of Sensor Sweet Spot Selection Algorithms

Phase I (Year 1)

Contract Number N00014-07-C-0144

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14. ABSTRACT

This Phase I effort was to develop weighting factors that characterize the quality of the WAA sensor's received data at various locations within the sensor's performance envelope. This effort involved extensive reviews and analysis of TECHEVAL and OPEVAL reports and other at-sea recorded data on WAA sensor performance. It has defined a detailed technical approach for locating, collecting, interpreting, formatting and restructuring the data into a Common Database. It also details the iterative relational analysis process utilized to establish predictable Sweet Spot contributors and to assess the positive affects of the resulting Sweet Spot tagged data. It is expected that the output of this research may trigger other Sweet Spot study efforts to dynamically demonstrate the resulting positive effect on contact solution generation capabilities.

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Executive Summary

In May 2007 General Dynamics Information Technology was awarded Contract N00014-07-C-0144 "Validation and Implementation of Sensor Sweet Spot Selection Algorithms" by the Office Of Naval Research (ONR) to develop a process to identify and quantify the tracking performance of an existing passive acoustic sensor subsystem (AN/BSY-2 Wide Aperture Array (WAA)), for contacts characterized by various received sensor parameters within the sensor's performance envelope. As a result of the analysis of those parameters, we proposed to develop quantifiable weighting factors; such that the sonar sensor's performance can be characterized based on a contact's location within various parametric and volumetric boundaries, defined by a set of ranges, bearings, bearing rates, Depression/Elevation (D/E) angles, Signal-to-Noise Ratios (SNR), and other possible parameters. The resultant weighting factors associated with the sensor data that is input to the various Target Motion Analysis (TMA) processing techniques will provide the ship's force with a higher confidence level in the quality of the resultant TMA solutions and a better picture of all contacts within the ship's battlespace, in addition to providing more rapid and accurate firing solutions on contacts of interest.

The focus of the first year of this research effort was on data collection, data definition and translation, database creation, the verification and refinement of previously defined WAA Sweet Spot parameters, refinement of the dynamic Sweet Spot, including additional contributions, and a demonstration of the positive effects on TMA capabilities. Due to the delays incurred obtaining existing recorded WAA tracker and developing tools to correct and/or adjust recorded data errors, we were not able to conduct a demonstration of the positive effects of the Sweet Spot on TMA performance.

This Phase I effort has developed the process of gathering, and formatting at-sea collected data into a Common Database (CDB), which allows further research into developing weighting factors that characterize the quality of the WAA sensor's received data at various locations within the sensor's performance envelope. A focal point of this research effort was the establishment of a well-defined and documented process for analyzing and validating the Sweet Spot criteria. We have established a process that is repeatable, predictable and can provide us with the basis for achieving verifiable results.

Gathering the at-sea data from Technical Evaluation (TECHEVAL), Operational Evaluation (OPEVAL) and other evolutions for submarines with WAA required extensive assistance from outside agencies and the establishment of the mechanisms required to transport that secure data to the General Dynamics Information Technology research facility. In order to determine what portions of that data for various runs would be cogent to our analysis required a virtual bit-by-bit review of recorded data files due to the wide array of data formats from ship to ship that had to be transformed into our CDB structure. As a result of this research effort recorded data are now standardized and installed in our CDB. While not all data is 100 percent compatible, methods have been defined to maximize the usefulness of all recorded runs.

Numerous special tools had to be developed to correct and/or supplement errors and /or shortcomings within some of the data content. These included data deficiency corrections for incomplete or missing pertinent data, environmental data, sound path correction, and non-

measurement error correction. A special tool, driven by data extracted utilizing capabilities implemented in the CDB, has been developed to assess the affects of sound path and related affects caused by deviations in D/E. Special tools and techniques have been established for defining and correcting what are considered to be non-measurement errors which result from conditions created by the data recording process and those which become a factor because of the increased accuracy of Sweet Spot data (e.g., sound path vice straight line, installed array offsets, etc.).

A user-friendly capability to query, using a full complement of relational statements, has been designed into the CDB. This is the primary method for identifying segments of data which meet defined interim Sweet Spot criteria and provides a standardized method to review and analyze a large quantity of data runs containing a variety of operating and environmental conditions. Additionally, a vast array of flexible and Sweet Spot analysis driven chart generation capabilities have been integrated into the CDB design with user-friendly chart manipulation capabilities, allowing the analyst to easily alter the presentation to focus on a particular area of concern. The chart generation capabilities are supported by capabilities to provide statistical quantification of data contained in the selected data segment (variance, standard deviation, average, etc.) There is an additional capability to place selected data presentations in a composite presentation, which greatly enhances analysis efforts.

The capability to perform a TMA assessment of Sweet Spot data has been installed and checked out at both the General Dynamics Information Technology Facility and at the Naval Undersea Warfare Center Division, Newport (NUWCDIVNPT) facility in Building 1171. While the capability to output data in a form compatible with both facilities is embedded into the CDB, the capability to properly tag all data to define each data item's Sweet Spot compliance areas was not fully implemented.

Only a preliminary analysis of selected portions of the available data were able to be performed due to Phase I resource constraints. However, some new contributing factors have been identified such as; D/E stability, rate of change in both bearing or range, individual array SNR (Forward-Mid (FM), Mid-Aft (MA) and D/E) vice and establish single composite array SNR, etc.

The capability now exists to perform a more detailed assessment of how Sweet Spot data can improve TMA performance with future at sea data, and we believe that additional data from USS Virginia TECH/OPEVAL as well as from an exercise in the Pacific currently being planned to evaluate onboard acoustic sensors on USS Cheyenne, could provide the additional data needed. We believe that since the process we have developed has been well defined and verified, an efficient iterative Sweet Spot assessment of a statistically significant number of data sets could be completed to verify, further refine, and validate the end product (i.e., Target Solution) when employing the Sweet Spot criteria.

1.0 Background

In May 2007 General Dynamics Information Technology was awarded Contract N00014-07-C-0144 “Validation and Implementation of Sensor Sweet Spot Selection Algorithms” by the ONR to develop a process to identify and quantify the tracking performance of an existing passive acoustic sensor subsystem, for contacts characterized by various received sensor parameters within the sensor’s performance envelope. As a result of the analysis of those parameters, we proposed to develop quantifiable weighting factors; such that the sonar sensor’s performance can be characterized based on a contact’s location within various parametric and volumetric boundaries, defined by a set of ranges, bearings, bearing rates, D/E angles, SNR, and other possible parameters. The resultant weighting factors associated with the sensor data that is input to the various TMA processing techniques will provide the ship’s force with a higher confidence level in the quality of the resultant TMA solutions and a better picture of all contacts within the ship’s battlespace, in addition to providing more rapid and accurate firing solutions on contacts of interest.

This effort was a result of an analysis, conducted by NUWCDIVNPT in FY03, of the AN/BSY-2 WAA performance during the AN/BSY-2 OPEVAL. Specifically, a question arose regarding the performance of the AN/BSY-2 WAA. That analysis indicated the capability for superior WAA TMA accuracy (i.e., a Sweet Spot in that sensor’s performance envelope) when certain basic sensor parameters meet specified criteria. It was postulated that the accuracy and time to a firing solution could have been greatly enhanced had the TMA operators been cognizant of, and could more effectively exploit, the observed specific operational criteria associated with the Sweet Spot.

The WAA sonar is a highly sensitive three-dimensional passive ranging sonar system that provides direct measurements of contact bearing, D/E angle, and range. The WAA consists of six externally mounted arrays with three placed on each side of a submarine platform with an inboard electronics subsystem to process the data. Passive ranging is performed using a technique called Wavefront Curvature Ranging (WCR). This technique compares the arrival times of a propagating wavefront at three different points (array centers) in a line and determines the curvature from the differences in arrival time. Once the curvature is known, the range from the signal source can be calculated. Target range and target bearing are then passed along to the TMA subsystem for further analysis of system solution (range, course and speed).

Previous analysis of many sets of WAA sea test data has indicated that Wave Front Curvature (WFC) range and tracker bearing accuracy are heavily dependent upon several parameters. The most important of these parameters are SNR, target relative bearing and target range. At-sea observations as well as theory have shown that range accuracy is best at high SNRs, target relative bearing around broadside, and short ranges. Despite these general known conditions, the impacts of their dynamic details have not been defined with tracker quality (particularly range) properly tagged, and current TMA algorithms have not incorporated meaningful weighting of values for bearing and range.

This Phase I effort was a follow on to the above analysis to develop weighting factors that characterize the quality of the WAA sensor's received data at various locations within the sensor's performance envelope.

This effort involved extensive reviews and analysis of TECHEVAL and OPEVAL reports and other at-sea recorded data on WAA sensor performance. The effort has defined a detailed technical approach for locating, collecting, interpreting, formatting and restructuring the data into a CDB. It also details the iterative relational analysis process utilized to establish predictable Sweet Spot contributors and to assess the positive affects of the resulting Sweet Spot tagged data. It is expected that the output of this research may trigger other Sweet Spot study efforts to dynamically demonstrate the resulting positive effect on contact solution generation capabilities.

1.1 Initial Investigation

In FY03, during a Senate Armed Services Committee (SASC) staffer briefing on the Director of Operational Test & Evaluation (DOT&E) Report on the AN/BSY-2 OPEVAL results, a question arose regarding the performance of the AN/BSY-2 WAA. As a result, PMS-350 posed the following question to NUWCDIVNPT: "Does the cost of the WAA justify the expense when it has such a large range error and what does it do to improve the performance of the ship?" PMS-350 requested a white paper that addressed the DOT&E identified range error deficiency, the cost versus benefit addressed by the SASC staffer, and the impact or pros/cons of doing a WAA range calibration.

In order to resolve the questions related to the excessive AN/BSY-2 TMA Time of Fire (TOF) range errors attributed to the WAA in that report, NUWCDIVNPT conducted an exhaustive review and analysis of all sensor measurement data collected during the runs outlined in the DOT&E report.

1.2 Findings

The conditions listed below summarize the findings from the resulting NUWCDIVNPT FY03 analysis. They identified the major contributors (relative bearing, range, SNR), but were inconclusive in defining the contributions the lesser known influences like D/E tracking/multipath, environmental conditions, etc. and the dynamic, interactive application of all these conditions. The process established for the research analysis, conducted during the Sensor Sweet Spot effort documented in this report, was geared toward providing visibility into the contributions of these known elements as well as attempting to determine and characterize other possible contributors.

The lessons learned from the NUWCDIVNPT FY03 analysis were as follows:

1. The WAA sensor is able to process bearing and range data over a major portion of the ship's 360-degree azimuth. However, to achieve the originally specified WAA sensor performance, the target must be within much more limited azimuthal sectors that are centered broadside relative to Ownship. Therefore, WAA sensor data processed outside those specified target azimuthal bands should be weighed much less by TMA than data collected within the specified bands if the TMA solution development accuracy is to be

optimized. There is currently little evidence this strategy is currently tactically employed during TMA solution development today.

2. It is required that the WAA tracker be allowed to stabilize, subsequent to assignment on target trace and upon entry into prime Sweet Spot areas. The data collected prior to stabilization should be considered inaccurate and the TMA function should weigh the WAA data before the tracker is stabilized much less than data collected after tracker stabilization. If this rule is not adhered to, TMA solution development will not be optimized.
3. Although WAA sensor bearing and range measurements are generated over a wide range of target SNR, previous analysis of sea test data has found that WAA ranging accuracy substantially degrades below a specific target SNR. Therefore, sensor data collected outside this minimum target SNR should be weighted much less than data collected above that specified SNR value during the TMA solution development if the solution range accuracy is to be optimized. There is little evidence that variable weighting of sensor data is being employed during TMA on tactical platforms.
4. WAA sensor ranging accuracy is specified within a defined range band. Several of the runs contained range data collected outside this range band, both before and after TOF. Data collected and processed by TMA outside the specified WAA sensor range band was found to be less accurate than that collected inside the range band. Much of the run data processed by TMA was collected outside that range band.
5. TMA was not designed to identify all the above constraints associated with WAA sensor performance. For the most part, TMA weighs sensor measurements equally, providing only very limited functionality to automatically filter unreasonable data. TMA operators are trained to eliminate outlying measurements they consider to be unreasonable, and those that disagree substantially with the majority of data collected by the sensor. However, there is no automated functionality to help TMA operators identify highly accurate range data from that which is likely to be suspect.
6. Because range data collected within the above specified Sweet Spot constraints oftentimes make up the minority of WAA sensor range measurements, TMA operators process a substantial amount of less accurate WAA sensor range data concurrently with highly accurate WAA measurements, thereby diluting the ultimate TMA solution accuracy.
7. Data provided indicates that time alignment errors approximating 40 to 50 seconds existed between reconstruction and Fire Control. These errors were present on the test platform for approximately 20 to 25 percent of the runs where time data was available. This implies that TOF target solution range associated with the test platform is likely different than TOF solution range associated with reconstruction. Therefore, TOF target reconstruction ranges for some runs, likely contain substantial range errors. This fact calls into question the actual errors calculated in the report, since those errors assumed the reconstruction range to be highly accurate.
8. For many of the runs, time synchronization errors between the test platform and reconstruction were unavailable. This currently makes it impossible to determine the

accuracy of reconstruction error associated with the majority of run data collected during the exercise.

In this report the term “Sweet Spot” refers to almost anything that embodies an optimum combination of characteristics and qualities, therefore, it is the most efficient, useful, popular, or the most lucrative entity in a group. What is a “Sensor Sweet Spot?” The Sensor Sweet Spot arises from a set of operational and environmental conditions which produce an optimal sensor output quality. These improvements can manifest themselves in either basic detection, bearing tracking or more sensitive measurements like the passive ranging features of the sensor. This research effort prominently focused on tracking capabilities with an emphasis on the more sensitive measurements which will likely present the greatest positive effect on TMA performance.

The Sweet Spot is very dynamic with the key parameters being range, bearing and SNR. These factors are variable on their own; but when other factors, such as Ownship speed, sound path conditions, range rate, bearing rate, individual (FM, MA and D/E) tracker stability, etc. were added, the window of “sweet” data can change drastically. For example, we may find a Sweet Spot probability area, but then if Ownship speed is high, we may find no situation that meets the Optimum Sweet Spot range accuracy criteria.

If we look at just the basic contributors, we find that with higher SNR values we will see a fairly large area, measured by relative bearing and range, meeting the Sweet Spot criteria. The measured bearings and ranges within the Optimum Sweet Spot area will exhibit accuracies conducive to meaningful solution generation from greatly reduced data sets. We notice that as the range and bearing boundary increases, there is a lower threshold. When this occurs, the area of “sweet” data is now lying outside the best zone. We can provide operational guidance for maneuvering to get the best solution, and automatically alter the solution generation processing approach to obtain the best possible solution given the existing data accuracy.

Figure 1 and Figure 2 depict hypothetical presentations of the Sweet Spot probability areas for both high and low SNRs respectively. As the SNR decreases, the area of probability for good quality data Sweet Spot decreases. Not only are the optimum Sweet Spot and surrounding useable areas size reduced, but the effects of lesser contributing factors increase.

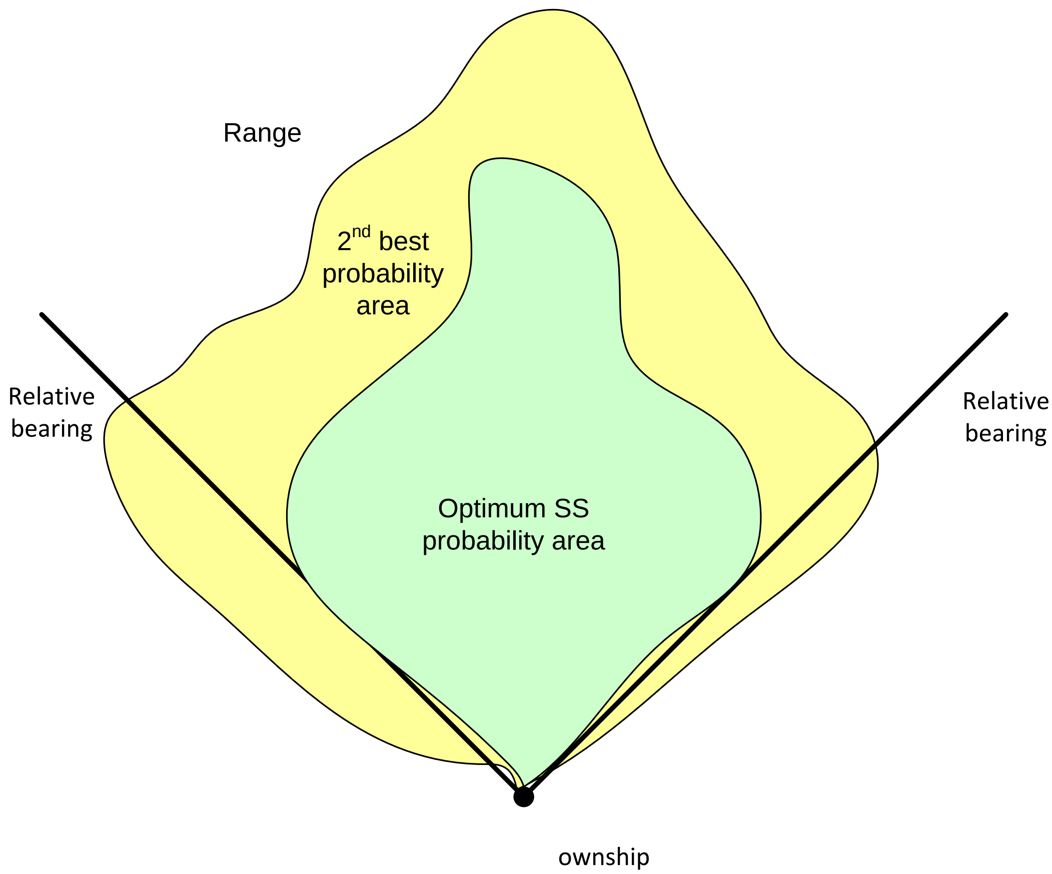

Figure 1. Sweet Spot Probability Area for High SNR

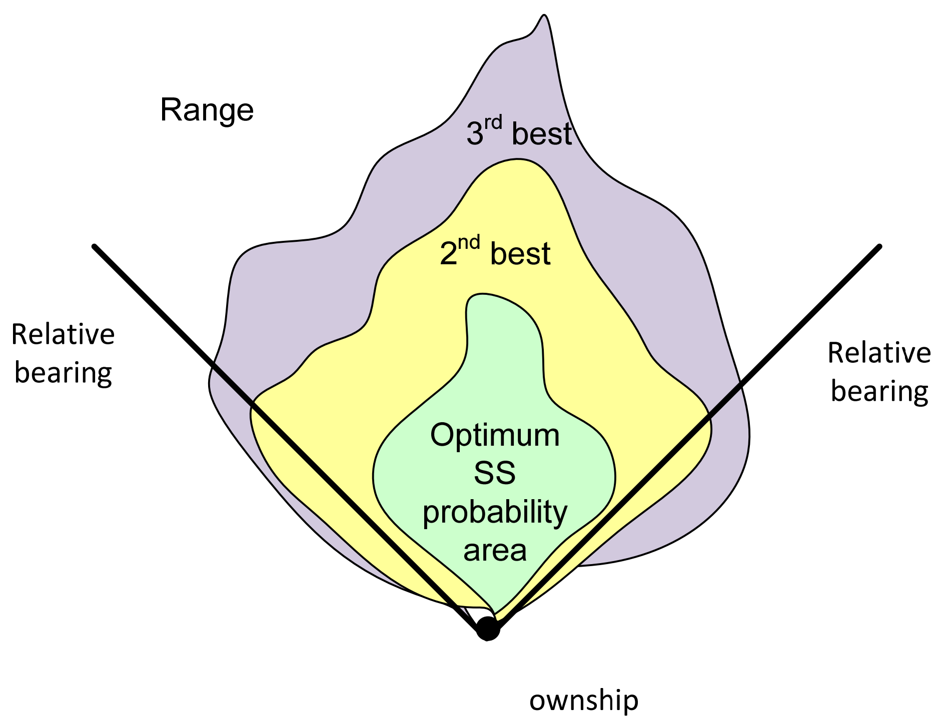

Figure 2. Sweet Spot Probability Area for Low SNR

While the FY03 analysis strongly indicated that the Sensor Sweet Spot does actually exist, this research effort has attempted to define the ideal combination of sensor data parameters, which when used to enhance today's sensors' algorithms, will provide operators with a more clear and consistent picture of the "best" area within that sensor to prosecute a contact in order to achieve the most successful weapon firing or contact location for position monitoring and/or collision avoidance.

While some of the key components defining the Sweet Spot boundaries are not only obvious (SNR, range, relative bearing), but have been proven, in a general sense, going all the way back to testing performed using the WAA Advanced Development Model (ADM), until now, the refinement of these factors and the definition of other considerations which could produce an acceptable probability of the prediction of when Sweet Spot conditions exist has been lacking.

A core objective of this research has been to establish a process whereby Sweet Spots can be determined successfully and routinely in any sensor. Once we have established the Sweet Spot mechanisms in the WAA, the usefulness and value of this research can be extended to other sensors: Acoustic, Electro-Optical, Infrared, Electromagnetic, etc.

2.0 Analysis Process Overview

The focus of this first year of the "Validation and Implementation of Sensor Sweet Spot Selection Algorithms" research effort was on data collection, data definition and translation, database creation, the verification and refinement of previously defined WAA Sweet Spot parameters, refinement of the dynamic Sweet Spot, including additional contributions, and a demonstration of the positive effects on TMA capabilities, if possible, within the funding constraints of this effort. The importance of a well-defined and documented process for analyzing and proving the Sweet Spot criteria was just as crucial and was the key focus in this first phase, and we have established a process that is repeatable, predictable and can provide us with the basis for verifiable results.

The complexity of that process was driven by the dynamic and diverse nature of the problem that needed to be solved. While the basis of the WAA Sweet Spot was clear (i.e., a high signal strength from a target off the beam with a reasonably short range to enhance the wave front delineation), these characteristics were applied to a review of existing reports originating from as far back as the WAA ADM, Weapon System Acceptance Trial (WSAT) and TECH/OPEVAL. The results of this review are contained in Section 3.3.2 and produced a two level range and single level bearing Sweet Spot criteria which was used for the initial queries of the collected recorded data files.

The process we developed utilized WAA recorded data from past exercises, to modify and apply dynamics to existing data parameters in order to identify additional potential Sweet Spot contributors. The interactive nature of the Sweet Spot contributing factors created a dependence on a large sample of data sets in order to accommodate a complete range of operational conditions (environmental and geometric). That search for applicable historical data resulted in data sets which only minimally satisfied our analysis needs, therefore, we were able to advance the concept but not totally define the Sweet Spot and all its associated dynamics. We believe that additional data from USS Virginia TECH/OPEVAL, and an exercise in the Pacific currently being planned to evaluate onboard acoustic sensors on USS Cheyenne, should provide the additional data needed. While the data from these events was not available for analysis during this first phase of this "Validation and Implementation of Sensor Sweet Spot Selection Algorithms" research effort, we believe that since the process we have developed is well defined and verified, a quick analysis could be completed to further refine the Sweet Spot criteria when this data is available.

The overall Research Analysis Process consisted of three interactive/iterative processes depicted in Figure 3:

1. Raw data collection, restructuring, storage and non-measurement error adjustment (Data Collection and Database Creation)
2. Sweet Spot Segment analysis and dynamic conditions definitions (Sweet Spot Analysis Process) and
3. Sweet Spot segment applications to TMA solution improvement (TMA Assessment Process)

The historical data used for this analysis was collected on a hull-by-hull basis, reformatted to a common structure, and then stored in a database. Because data analysis history has demonstrated the possibility of errors in recorded data which may not apply to the actual sensor measurement, we had to factor this into our process. The analysis process recognized the potential impact of these errors and made every effort to identify their existence and adjust the data accordingly where possible. These errors are referred to as non-measurement errors throughout the remainder of this report. All stored runs were assessed for these errors using existing and newly developed tools/techniques to identify and correct or define a compensating approach to reduce the effects of these non-measurement errors.

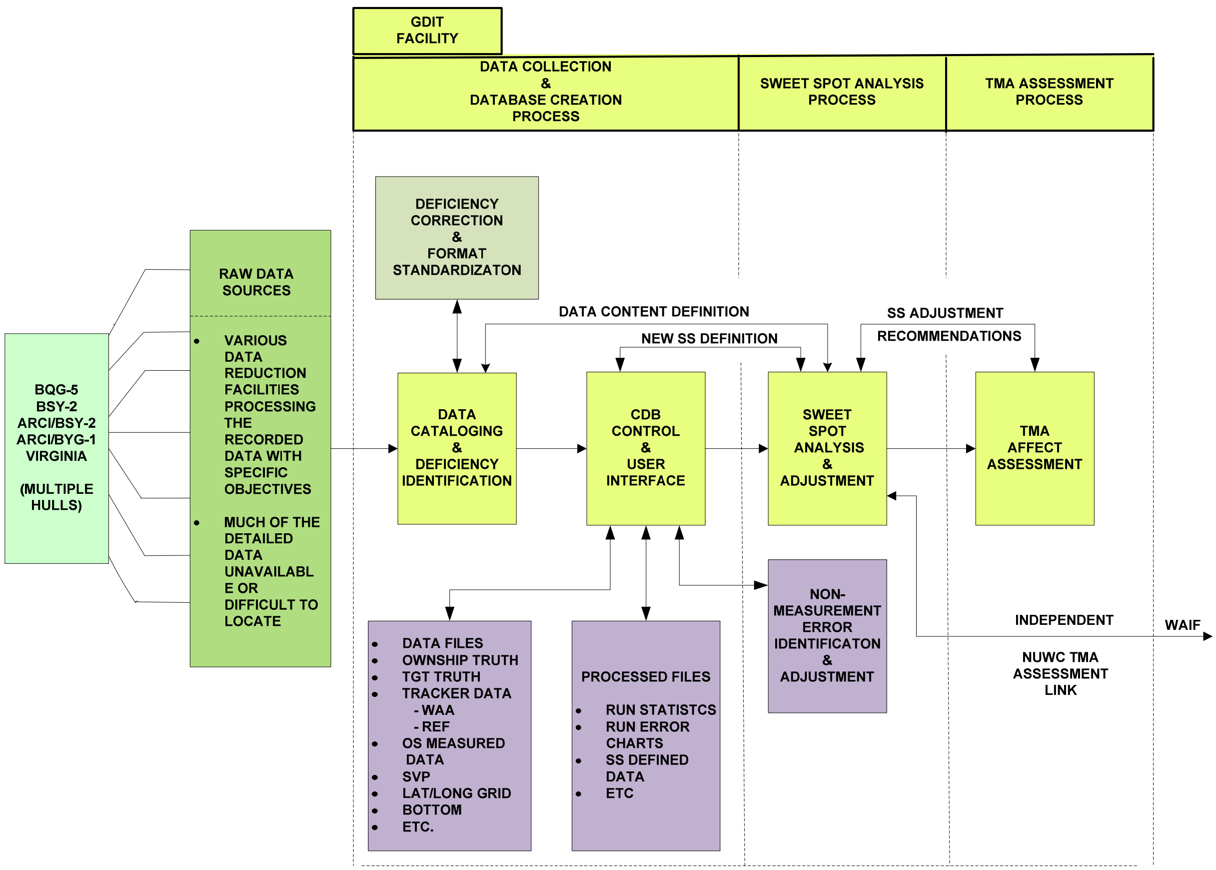

Figure 3. Overall Process Flow

2.1 High–Level Constraints and Assumptions

This analysis effort was limited to the WAA installed with AN/BSY-2, AN/BQG-5 and Virginia Class Combat Systems. It focused on the definition of predictable dynamic Sweet Spot characteristics and the verification of the resulting improvements to overall TMA capabilities. Where possible, existing information and tools were used.

Other high-level assumptions were that there would be:

- An adequate availability of existing recorded WAA tracker data containing data elements defining Ownship truth, target truth, detailed WAA tracker package, onboard Ownship data, environmental conditions including, at a minimum, bottom contributors and Sound Velocity Profile (SVP) and special conditions noted during the recorded exercise.

- Access to a baseline Combat Control System that contained the basic TMA functions of:
  - Multi-Measurement Performance Evaluation Plot (PEP) and Modular Automatic Test Equipment (MATE)
  - Background solution processing; i.e., Modified Polar Kalman Statistical Tracker (MPKAST) and Mission Level Evaluation (MLE)
- Access to existing tools to adjust recorded data errors resulting from incorrect truth, erroneous offset, improper environment reconstruction and/or incorrect operator setup conditions, specifically tool(s) to:
  - adjust all truth data based upon defined contact position error
  - redefine all tracker data for changes in array offsets
  - adjust tracker data for erroneous operator entry of local sound speed when there is a sound head failure (done automatically otherwise)
  - adjust tracker data to reflect sound path vice straight line characteristics
  - adjust erroneous time bias recorded and/or truth data.

2.2 Data Collection Process Objectives

The Data Collection Process consisted of several interactive procedures and the coordination of the efforts of multiple organizations/agencies. This process began by locating recorded historical WAA tracking data and culminated with a “user-friendly” distribution of criteria driven data query results. The steps developed to achieve and prove that process were developed to meet the overall process goals, not only between the interdependent activities within the process itself, but also to accommodate those contributions required from other major process areas. The coordination of all these contributors (internal and external) was anticipated to be a major effort and proved to be more difficult than expected. The following is a list of the process segments defined for this effort. The details of each process segment are documented in Section 3.

- Data Definition and Acquisition
- Environmental Data Definition
- Sound Path Computation
- Non-Measurement Error Update

The resulting process and procedures are compatible with potential future data sets from USS Virginia TECH/OPEVAL and upcoming USS Cheyenne sensor evaluation runs in the Pacific when that data becomes available to any follow-on to this research effort.

2.3 Sweet Spot Analysis Process Objectives

The Sweet Spot Analysis was the heart of this research project and consisted of five major activities:

1. First, charts generated by the Data Collection Process were reviewed and the applicable WAA and Reference Track data sets were defined and used to control the inputs to the CDB.
2. Once the data was populated within the CDB, the necessary charts and supporting data were selected for the non-measurement error assessment. When these error conditions were defined and a data adjustment approach was developed, the resulting adjustments were provided to the Data Collection Process for a CDB update. If no adjustment capabilities existed or were needed, the assessment results along with any required workaround guidance were documented and incorporated into the Sweet Spot Analysis data set.
3. We developed a tool which calculates sound paths for both the calculated optimum and the D/E measured path (including potential multi-paths around each). The results of these runs were placed in the CDB and became an integral part of the path and D/E contributions to Sweet Spot.
4. With the updated and error reduced data residing in the CDB, the Sweet Spot analysis was able to begin. The actual analysis consists of a combination of visual presentations supported by statistical computations. The desired content is selected using a relational extraction of the iteratively updated analysis driven Sweet Spot parameters.
5. When individual runs achieve the defined level of Sweet Spot bearing and range accuracy, they are passed to the TMA Assessment Process for further evaluation.

The key points of this analysis process are that it provides the basic groundwork in the ultimate goal of establishing the degree of potential tracker accuracy that can be expected from the WAA when definable criteria have been met. The data applied and the analysis process we have implemented focus on the measuring capabilities within the WAA and attempts to remove data error characteristics reflective of either recording deficiencies or tracker processing design limitations. Section 3 will provide additional detail related to the specific actions taken to achieve the objectives in each of the five major activities listed above.

2.4 TMA Assessment Process Objectives

The TMA contribution to the Sweet Spot Analysis Process lies in achieving an overall effectiveness measurement of the tagged Sweet Spot data. The brief segments of qualified run data and the resultant cumulative content of Sweet Spot qualifying data elements forced us to face the question of the usefulness of this data even when accurately predicted. But by injecting identical sets of tagged and untagged data and comparing results in a controlled TMA environment, the effects could be measured and valuable results obtained. These results were then analyzed and the findings were applied in the manner expressed in one or more of the three steps listed below:

1. The results reflect a significant improvement using the existing Sweet Spot tag criteria and the TMA data filtering and application to key algorithms produces acceptable results. This particular run will be set aside and only be rerun if other analysis produces changes to either the Sweet Spot tag criteria or TMA handling.

2. The results do not indicate an effective improvement and a review of the data and possibly associated data editing indicate a need to alter the Sweet Spot criteria. The related information will be transferred to the Sweet Spot Analysis portion of the process and needed changes evaluated.
3. The results do not indicate an effective improvement and a review of the data and possibly associated data editing indicate a need to alter the handling of the Sweet Spot tagged data with TMA. The related information will be used within the TMA Assessment Process portion of the process and needed changes evaluated.

Any combination of the above results and actions are possible and may be addressed concurrently. The TMA Assessment Process accommodates the coordination of all actions and the retention of a complete record of data set (run) status.

3.0 Analysis Process Structure

Technical teams responsible for each of the major components of the analysis process were assembled and their roles and responsibilities were briefed and defined in the Research Plan for this effort. The requirements for this first phase of the research effort were to; (1) establish a facility to handle the data collected and house the CDB and TMA capabilities, (2) collect and standardize historical data, (3) create the CDB, (4) establish the mechanisms to efficiently query and analyze the data to define and refine the Sweet Spot conditions and (5) provide a TMA capability to better define any operational optimizations. These efforts are partitioned into the four listed responsibility areas:

- Facilities
- Data Collection/DB Creation Process
- Sweet Spot Analysis Process
- TMA Assessment Process

Each responsibility area had a technical leader who worked with the Systems Engineering Technical Lead to direct and support the mission of the respective teams. Their specific tasks and overall analysis approaches are defined in the supporting paragraphs of Section 3.

3.1 Facilities

A facility was established at General Dynamics Information Technology in Middletown, RI to provide the physical capability to store the vast amount of supporting data, efficiently perform all analysis processing, and house the required Combat Control TMA baseline TI04 capabilities. Additionally, modifications were coordinated with NUWC to provide two-way data transfer capabilities between the General Dynamics Information Technology facility and NUWC. This interface was vital to support the transfer of raw data to General Dynamics Information Technology and tagged data to NUWC for their independent assessment. Figure 4 provides the installation equipment and software contained within the facility and associated functional connectivity for the data collection and database creation process.

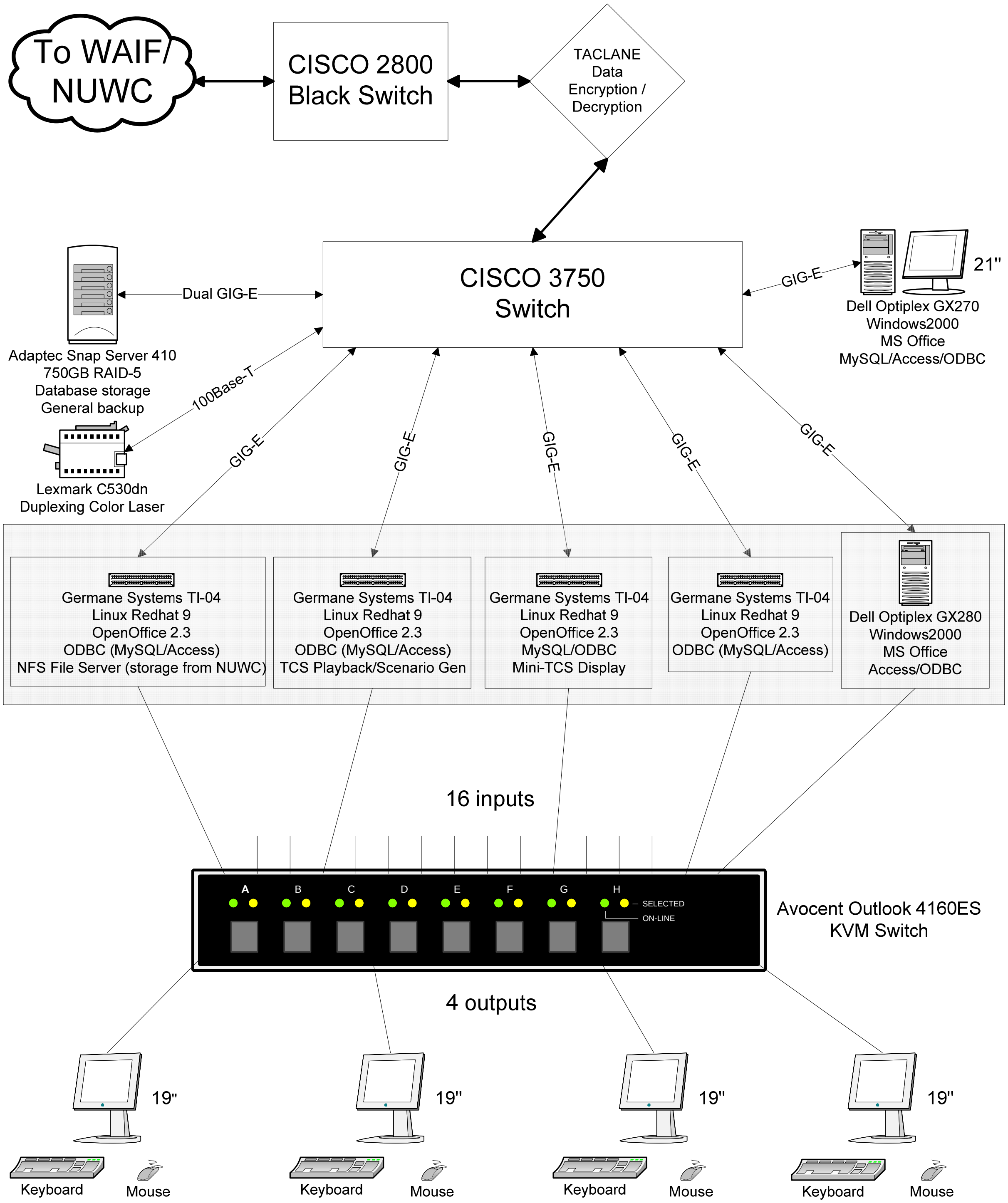

Figure 4. Data Collection and Database Creation Process

The Data Collection process included the identification of potential sources and collection of applicable recorded data, restructuring that data into a CDB and modifying the data content to extract non-measurement error conditions. Figures 5, 6, and 7 depict the processes used for collecting, restructuring, and storing data into the CDB and the eventual input of data alterations deemed necessary because of data errors caused by non-measurement factors.

3.1.1 Data Collection

The Data Collection phase was separated into two parallel paths once data was received and stored at the General Dynamics Information Technology Facility. One path prepared the data set for installation into the Tracker, Ownship Navigation (NAV), Target (TGT) Truth and Ownship Truth segment of the CDB, while the other prepared the data associated with the run related environmental conditions. The following paragraphs define the key actions taken to accomplish the above objectives.

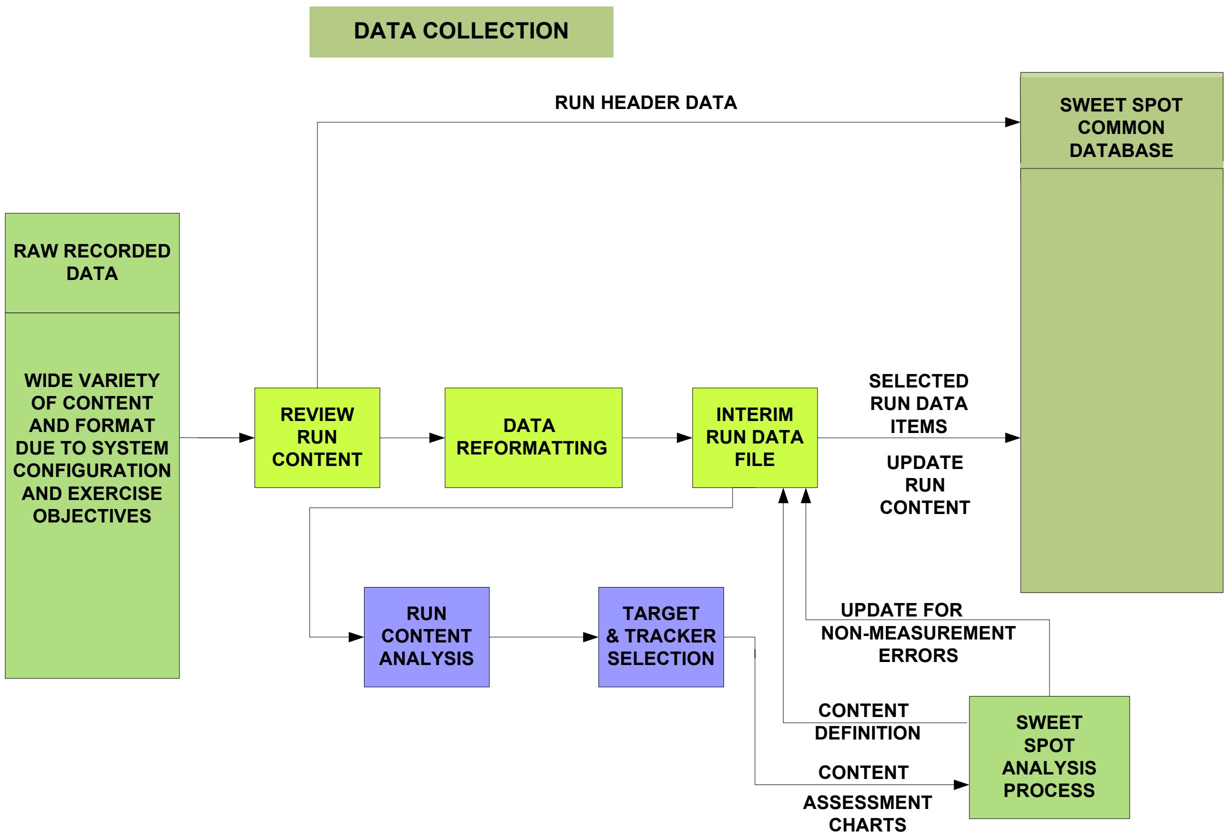

Figure 5. Input Data Processing

3.1.1.1 Data Definition and Acquisition

The historical recorded data was obtained via the query of known experts in the various exercise type data recording operations. Additionally, in many cases, these same personnel were enlisted to assist in obtaining data based upon a team defined data requirements list. Much of the data identified had deficiencies when compared to the defined requirements, but a process was developed to assess and apply all data sets, complete or not, and the resulting following approach evolved.

The primary data input path was established via NUWC over the Wide Area Integration Facility (WAIF) network to General Dynamics Information Technology's secure lab, directly onto a Linux machine or by hand-carry electronic storage medium, such as a CD or DVD. The initial objective was to define the data collection end product CDB format to drive the restructuring of all input data types and content. The initial format selected was derived from the AN/BSY-2 WAA tracker, Ownship NAV data and other environmental data messages. This was a logical selection because AN/BSY-2 would likely provide the bulk of the historical recorded object data in either the legacy or integrated Acoustic Rapid Commercial Off-The-Shelf (COTS) Insertion (ARCI) form (basically common message formats). When the lab was undergoing setup activities the NUWC-provided (DDSC-IS) data types were the only packages available to begin construct of the CDB and the intermediate processes to achieve the goal of an interactive Graphical User Interface (GUI)/CDB that could ascertain Extract, Transform, Load (ETL) and assimilate/analyze heterogeneous raw data sets toward the definition of the WAA Sweet Spot. In particular, MySQL, Python, Open Database Connectivity (ODBC)/Java Database Connectivity (JDBC) modules, OpenOffice 2.3 and Linux Report Program Generator (RPG)/binary updates were necessary to enable the General Dynamics Information Technology lab to achieve the desired results. Once these updates and setups were accomplished and tested, the initial data load of in-house NUWC data began.

The initial process was established using the NUWC provided DDSC-IS data from USS Virginia Class and USS Connecticut. The approach was later adapted to all input data types and structures. The file format is evaluated and the files are extracted, if necessary. If the files are in a non-binary format such as a spreadsheet or Comma Separated Values (CSV), then one of the files is examined directly in a spreadsheet program, such as MS Excel, or OpenOffice Calc on Linux. Within the directory structure there are sometimes support files that give an overview of the type of data received and the hull, sonar system, date of test and other information. A combination of what is contained within those support files and what appears to be inside the actual data files dictates the handling of the data files. For example, if the files are for a data type that has been previously processed, then that process will be used on the new data. If the format appears to be new, then the data is evaluated within the spreadsheet application. If the data cannot be opened natively by a spreadsheet application, then the supplier of the data is contacted to determine if a tool or a process is already in use by the supplier that will allow full extraction of the data.

3.1.1.2 Initial Data Assessment

Working with key personnel at the various data source sites, the incoming data was carefully reviewed and high level definitions of required content actions were applied. These actions resulted in the construction of run header data files containing at a minimum, the following items:

- Exercise Type:
  - Sensor Calibration/Accuracy
  - On Range Weapons
  - On Range Free Play
  - Open Ocean
- Hull and Combat System Revision
- Date/Time of Exercise and Individual Run

- Specific Location (Lat/Long) of Individual Run
- Geometric Conditions including TGT/Ownship X,Y Charts
- The Range of key measured values:
  - Relative Bearing
  - TGT Range
  - SNR
  - D/E Angle
  - etc.

Once the data is in a state where it can be evaluated, it is examined in detail to determine what items or records may be missing in accordance with requirements contained in the CDB Specification. There are three main sections of data for each data type as defined in the CDB:

1. Ownship Navigation
2. Range/Truth
3. Tracker/Sonar

Missing items must be assessed and dealt with for each section. In some cases, the data supplier will be able to supply the missing pieces. In other cases, the gaps in the data can be mitigated by calculation, or substitution. For example, in one data set, the only water-referenced Ownship NAV data were values for Ownship heading. All other key water referenced parameters were generated using available ground reference values and then compared and adjusted using historical ocean conditions. In this case, some error injection was anticipated and affected data items were appropriately tagged.

The Functional Analysis database, which is a NUWC defined database structure, was initially used to extract DDCS-IS data from SQL files that contained over 180 separate data tables. We used this as the starting point for constructing the CDB and used the AN/BSY-2 to ARCI software interface document to append data elements that would be needed to perform Sweet Spot analysis. This process was implemented as follows:

1. We used the source DDCS-IS SQL files as is to create a TRUE raw representation of the NUWC provided data. This meant that all 180 data tables were extracted to a MySQL database. It can be assumed that this is an intermediate database of which a second step, Python script named fill_database.py, would extract NUWC TMA data into their Functional_Analysis DB. Start and Stop dates in Universal Time Coordinated (UTC) are input parameters to this Python script. This was accomplished and there exists a database called Functional_Analysis in General Dynamics Information Technology's MySQL database. This format was deemed important to keep/use so that General Dynamics Information Technology could replicate modified Sweet Spot data back to the NUWC TMA standard if required.
   a. Upon analyzing the fill_database.py script, we realized that there were 6 to 10 of the 180 raw data tables that were being used, and that only a fraction of the data elements (fields) within those tables were being used.
   b. Upon further analysis of these 6 to 10 data tables, we realized that 4 of these (OwnshipData and WAATrackerStatus along with cvRContactEventProperties and cvRContactReportProperties) nearly matched the AN/BSY-2 to ARCI Software Interface document message blocks. Therefore, we maintained that using these

DDCS-IS data definitions for the CDB OwnshipNav and CDB Tracker tables ensured that all possible/probable data elements would be defined and eligible for use in the Sweet Spot CDB analysis.

2. The original AN/BSY-2 OPEVAL data was now available and restructured, and in some areas reconstructed into this new format. Data received from exercises recorded on the Atlantic Undersea Test & Evaluation Center (AUTEC) Range was still undergoing setup for the extraction phase and once ready, was set up for the transformation phase based on this new, improved and enhanced data capture database structure.
3. Truth data for NUWC-provided data was still missing at this point. NUWC communicated that DDCS-IS data included TSUNAMI-AUTEC Pargos files that contained truth data for all event runs. Also provided were technical support and tools including the Range Truth Reader (and supporting files like math.py) which populated the tblTruth and tblContactTruth tables in the Functional_Analysis MySQL database. Minor data manipulation was then executed to append this data to the CDB Truth tables.
4. Any DDCS-IS data that may be provided to the General Dynamics Information Technology Sweet Spot project would now be easily ETL'd based on the process that manifested from this data type.

To further enhance and automate the Initial Assessment Process and provide a means to rapidly review data content during the Analysis Process, the following tool was developed. The CDB was designed around the premise that it will house a large quantity of very diverse data sets. Because of the diverse nature of the data and the various formats in which the data arrives, an analyst may not necessarily have a preconceived idea of where to begin. One tool that the CDB provides is an enhanced charting capability. However, when the CDB is filled to its designed potential, it may be far too cumbersome for the Sweet Spot analyst to examine hundreds of charts to find a good candidate for evaluating the Sweet Spot. Therefore, the CDB provides a tool which gives the analyst a high-level, tabular summary of all of the data within a single event, for all runs and all WAA trackers. This capability is referred to as "Statistics" within the CDB. The analyst selects the event and is able to define a window of desired results for WAA SNR, WAA DE and truth range. The goal is to allow the analyst to, for example, reject data where the WAA SNR is below or above a certain threshold, and the same idea applies to WAA DE. Truth range is included in case the analyst wants to exclude data that is close range, far range or both. Each of these criteria is combined with a logical AND statement, meaning the statistics tool requires ALL of the criteria to be met before it counts the data item. Examples of representative statistics are provided in Appendix B, Figure 1. Each line of data is sorted by run, then contact group, then WAA tracker. The total percentage of data available under that definition that also meets all of the criteria previously specified is shown as "% Total." That percentage is also broken down into port-side and starboard-side relative bearings. The minimum and maximum relative bearings for each side are shown. Next, the actual minimums and maximums of SNR, DE and truth are shown directly below the criteria that were typed in by the user. Finally, a sentence combining the total number of data samples (in minutes), SNR and DE average and standard deviation appears at the bottom of each row. For any run in which contact group and WAA tracker combination has no data meeting the criteria, no entry appears.

At the end of this process, if any gaps remain, the areas of the data that contain those gaps must be labeled upon importation into the CDB. Labeling typically consists of using an agreed-upon value that lies outside the expected range of values; this place holder value will vary depending on the data field in question. In some cases, the gaps may be so numerous that the data set is not imported into the CDB but kept for the potential of filling in the missing data in the future.

At this point the process splits into parallel paths to address in one case the environmental/ocean conditions (LSS, SVP, Bottom depth/Contour, etc.) and in the other case Ownship/Target elements (Tracker Data, Ownship NAV Data and Ownship/TGT Truth).

3.1.1.3 Data Content Establishment

A number of the runs had tracker data of no value to the WAA Sweet Spot analysis and would only cause clutter in both the database and analysis presentations. This step initializes the process for elimination of this excess data. The primary tool used was a truth-versus-tracker bearing chart for all contacts included in the run data. This chart is constructed and passed to the Sweet Spot Analysis Process in which the usable content was defined by the Subject Matter Expert (SME). Upon receipt of the content definition the specified usable tracker data sets were extracted for further processing.

Since the current platform for hosting the CDB is Microsoft Access, the most natural way to analyze the data is in a separate MS Access database, which can be considered as a "pre-CDB" state. Spreadsheet applications, such as MS Excel and OpenOffice Calc, have a limitation on the maximum number of rows supported per worksheet (typically about 65,000). This limitation is not crippling in every case; however, it is usually an issue when the data set received is not adequately broken down into logical segments. Some data sets just contain large quantities of data, even after the pieces have been grouped into runs. In all cases it is necessary to split up an event into separate runs, if it has not been done so already. It is especially advantageous to do so when the event contains a large amount of data. One logical method of determining run break points is to plot the X and Y position of the Ownship and any targets. Based on the Ownship maneuvers, runs can be created such that one run may contain a meaningful set of operational conditions and separate key potential Sweet Spot contributors, such as providing a high rate of relative bearing change. In those cases of long runs with high quantities of data, only pieces of the data set can be practically manipulated within a spreadsheet application, and then the results are applied to the entire set within the Access pre-CDB.

Each of the non-flag/bit fields in the CDB has an associated and desired unit of measure. An important part of the CDB data input process is keeping track of those units. Data that comes in may be in any of several units. The assumption cannot be made that the "usual" units for a given piece of data will apply. If the data field definition is inadequate, or thought to be incorrect, then comparative analysis can usually determine the unit type. For example, latitude and longitude can be converted to two-dimensional linear measure, like an X-Y Cartesian plot, or a rate like knots, yards/sec and so on. Latitude and longitude can also be used to calculate and verify the course field by breaking down by record each movement in latitude and longitude into linear measure, taking care to account for the linear distance change as defined by geographic position. Then, forming a right triangle, the angle is computed. The length of the hypotenuse of this triangle is the velocity over ground. In some cases, the data supplier may be able to provide a clarification of units. One source of confusion was determining whether certain data items were referenced to the ground or water. Water-referenced movement does not take into account the water current vector magnitude and direction (set and drift) and ground-referenced movement does. In sorting out this issue, there were three main categories for truth movement that could be measured in either ground or water reference: X-Y position, heading (water)/course (ground), and speed (water)/velocity (ground). There are many ways to rectify this uncertainty. Latitude and longitude, for example, are referenced to the earth and, thus, are ground referenced. Lat/long position can be correlated to any ground referenced measurement.

3.1.1.4 Data Deficiency Correction

All data sets were then reviewed to establish content and format. Once the content was evaluated and any "holes" defined, a variety of procedures for creating these missing data items had to be established if there were no tools that existed to handle those situations. The following list represents a few of the major data deficiency areas addressed:

- No Relative Bearing
- Incomplete Water Reference Ownship/Target Data
- Incomplete Ground Reference Ownship/Target Data
- No Ownship/Target Truth Data
- No Tracker Mode indication
- No Truth Bearing and Range
- Many Cases of Data Valid Status Indication Missing, etc.

At this point, all the data types are defined and missing data was dealt with to the extent possible. The data sections of Range/Truth and Tracker/Sonar have specific interdependency relationships that need to be defined. Because the basis of Sensor Sweet Spot is comparing actual sonar/tracker performance to what actually happened, each piece of tracker data must be mated with the corresponding piece of truth data. In other words, the data that comes in is not necessarily pre-correlated. Phase I of Sensor Sweet Spot begins with this process, and thus is highly reliant on this process to be completed accurately. As such, for any data that is not pre-correlated, human interaction must take place and declare the elements of truth and tracker data that correspond with each other. This step requires someone who is familiar with sonar (specifically WAA) trackers. For each piece of truth/range data that correlates to one of the targets, the CDB considers that as a "Contact Group," but the concept is not unlike the sierra number. Once each contact group has been defined, the next step is to pick out, among all of the available sonar data, which trackers go with that contact group. This is done by graphing true bearing versus time as shown in Appendix B, Figures 2 through 5. and overlaying the true bearing of the target as reported by the range (the truth data) with the actual tracker data, which comes out of the sonar system. When more than one target is present in a test, and their true bearings are relatively close or crossing, trackers may switch targets and thus will have to be re-allocated to the appropriate Contact Group.

The amount of time a tracker is on one target must be analyzed and thus incorporated into the CDB. That way, when Sweet Spot analysis begins, the analyst can call up a contact group and all associated trackers, without having to look through a lot of data that pertains to another contact group (or no contact group as is the case when sonar tracks a commercial vessel). This process is done for WAA trackers and, when possible, one tracker of another sonar type (typically the Sphere), is selected and correlated. This non-WAA tracker is referred to as a reference tracker and used primarily to evaluate sensor bias conditions. When all WAA trackers have been correlated to contact groups and if a reference tracker has been assigned, all remaining sonar data is marked as unassociated. It is not discarded but does not appear on any graphs and is not used in any way by the CDB. It remains available for a potential future use. All tracker assigning and time cropping is done in the pre-CDB realm; however, CDB has the capability to modify the groupings and time cropping in a user-friendly way.

3.1.1.5 Final Data Translation

The data files which have received the processing defined in Paragraphs 3.2.1.1 through 3.2.1.4 were then translated to the CDB format and all compatible fields installed into the CDB. All CDB fields which we were unable to value were properly identified in the CDB such that any attempts to access that data will produce an error condition to the request initiator.

3.1.2 Environmental Data Definition

Although not specifically defined as a Sweet Spot contributor in the initial definition, the operating environment can often be a core contributor to Sweet Spot predictions and qualifying data quality. The analysis process will rely on the best possible definition of the environment and bottom conditions. Many of the incoming data sets do not have a complete recorded package of needed data, but when these deficiencies exist, historical SVP and Bottom Contour information were inserted.

3.1.2.1 Environmental Data Assessment

Although every effort was made to define and acquire complete environmental and bottom contour data content established during the exercise, reality has proven that in many cases a complete package was not provided. Therefore, the extraction from the historical database option will be the most common approach. The following actions have been established to handle all data availability conditions plus provide some "sanity" checks to increase confidence in the resulting selected data elements:

- Interrogate the source-supplied data set and identify all exercise measured/recorded values for LSS, SVP, Bottom Depth and Bottom Contour
- If SVP data exist, extract the files in place in temporary store with the associated Lat/Long and Date/Time
- If Bottom Depth recorded values exist, place into added field of the Ownship NAV File and set aside for later sanity check
- Extract Historical SVP and Bottom Contour information from the Historical Database
- If recorded sensor values of LSS exist, compare each sensor value to the interim selected SVP and resolve issues (sanity check)
- Interrogate the LSS contained in the WAA Tracker File, compare to the selected LSS and resolve issues (sanity check)
- Compare Bottom Depth measurements to Historical Data and resolve issues (sanity check)

3.1.2.2 Environmental Data CDB Insertion

Environmental and bottom data was installed in the CDB in a grid oriented form. Each run within every exercise defined the Lat/Long boundaries and the appropriate grid was then placed into the CDB. The Historical Database was accessed and the bottom contour for the Lat/Long Grid was extracted and also stored. At this point the measured bottom depth (if present) was compared to the contour conditions installed. Finally, the SVP characteristics distributed over the defined grid were evaluated, and needed boundaries for SVP change were established. The necessary SVPs (historical or measured as defined in 3.2.2.1) were then installed in the CDB.

3.1.3 Sound Path Computation

One of the primary and definable symptoms of the environmental conditions addressed in Section 3.2.2 is the actual sound path from the target to Ownship. For purposes of this analysis, it can produce not only non-measurement error adjustment by defining the differences between a straight line and actual sound path between target and Ownship, but more importantly, the potential effects of multi-path conditions on the actual Sweet Spot definition. The sound path computations and related data item injection into the CDB supports all analysis efforts. A tool was developed which will access the defined SVP (Section 3.2.2) and bottom files and extract CDB values for Ownship Depth and Target Depth and Range to produce the following listed data items for all data samples within the set (normally 1 sec samples):

- Optimum D/E (strongest path (D/E Truth))
- Optimum D/E - 1 (+ D/E with next highest signal strength)
- Optimum D/E - 2 (+ D/E with second highest signal strength)
- Optimum D/E - 3 (- D/E with next highest signal strength)
- Optimum D/E - 4 (- D/E with second highest signal strength)
- Optimum D/E Path Length
- Optimum D/E - 1 Path Length
- Optimum D/E - 2 Path Length
- Optimum D/E - 3 Path Length
- Optimum D/E - 4 Path Length
- Measured D/E (from Tracker Data)
- Measured D/E - 1 (+ D/E based upon measured D/E Variance)
- Measured D/E - 2 (+ D/E based upon measured D/E Variance)
- Measured D/E - 3 (- D/E based upon measured D/E Variance)
- Measured D/E - 4 (- D/E based upon measured D/E Variance)
- Measured D/E Path Length
- Measured D/E - 1 Path Length
- Measured D/E - 2 Path Length
- Measured D/E - 3 Path Length
- Measured D/E - 4 Path Length

These data items are placed into the Tracker data file for easy access during the analysis process.

The sound path tool (Refer to Appendix E) was developed and has the capability to calculate several things when given an input of time, Ownship position and depth, target depth and range, true bearing of target, target position and measured D/E angle to target. A CDB output tool will read the CDB to provide the following inputs: historical SVP at both the Ownship and target positions, historical bottom depth at Ownship and target and user-definable linear increments between each, calculated bottom slope, a forward ray trace defining path length at user definable increments +/- the measured WAA D/E, and Eigenray trace at the truth-specified target range sorted by signal strength, also providing path length.

The output of the sound path tool is read in by the CDB and each piece of data for every sample that was given to the tool is stored with the correct event, run, contact group and WAA tracker. If an increment of anything greater than 1 second is used, the CDB will duplicate the data until the next time increment is reached. This method prevents data gaps from becoming a problem. When measured data for SVP or bottom depth is available, the CDB will use that value instead of historical, or it may be overridden. A flag next to each section identifies the data as historical or measured.

While examining range accuracy, an analyst may suspect an error in D/E angle as a potential contributor to inaccurate range. Any point on the D/E plot may be chosen, which will allow the analyst to access the sound path data (such as SVP) associated with that data point. The analyst could also compare measured D/E with the calculated truth D/E.

The ability to call the sound path tool is part of the CDB interface, but is intended to be completed before the analysis of a data set begins. The operator chooses the overall event, the run within that event, the contact group of interest within that run, and finally the WAA tracker of interest that is correlated with that contact group. Next, the user specifies a time increment for data output with a minimum of 1 second. An input file is generated and the sound path tool is launched. Processing a very long run or a fine time increment may take minutes or hours, which is why it is advantageous to run this ahead of analysis.

3.1.4 Non-Measurement Error Update

The Data Collection Process was responsible for injecting data element corrections produced by the Sweet Spot Analysis Process to remove non-measurement errors. This responsibility includes the documentation and tracking of all changes to the data sets even when those changes might have been inserted by one of the other process areas. The actual steps taken for identification and correction of non-measurement errors are presented in Figures 3 and 4 and were normally performed outside of the Data Collection Process. Once the corrections were inserted, the runs were separately installed in the CDB and cataloged by applying a run modification number. At this point, both the initial and modified run content resides in the CDB.

3.1.5 Database Creation

This process area was responsible for creating the database to house all of the data and to define the schema, query structure, sorting functionality and all other data manipulation requirements for the database. The responsible personnel ensured that this relational database was maintained and backed up at regular intervals.

This process relied on a database SME (to establish the database, its structure, user requirements and maintenance plan). The SME was then responsible for adding, enhancing new queries and sorting and making architecture alterations in the event any major CDB change was required. In short the database SME and the Database Creation Process were responsible for all activities concerning the construction and utilization of the CDB.

3.1.5.1 Basic Data Content and Considerations

Key information concerning the content of the CDB is listed below. In most cases the data set was supplied by the Data Collection Process and forwarded in predefined format and content. These points re-iterate many of the previously defined data considerations and add items unique to the CDB.

1. All data was analyzed and stored on a hull-by-hull, recorded data exercise type, date/time of run and software version basis. Most data adjustments were impacted by one or more of these features; however, relational queries and other database access requirements were not restricted by this partitioning.
2. An early effort, working with Data Collection, was directed toward the creation of a matrix which used the recorded data items as clues to decipher potential non-measurement errors. For example, the system SVP indicates an incorrect LSS being used when the Ownship X, Y, Z position is identical to the Sensor X, Y, Z, etc.
3. The tracker data sets defined include the following data elements:
   a. Time
   b. Bearing (True and Relative)
   c. Bearing Rate
   d. Range
   e. Range Rate
   f. D/E
   g. SNR for Dual Loop, FM, MA and D/E
   h. Sensor X, Y, Z Position
   i. Track Quality Indicator (TQI)
   j. Tracker Mode (Manual, Automatic Track Following (ATF), Global Tracking Trigger (GTT), etc.)
   k. Validity Status for all Key Data Items
   l. Variance/Standard Deviation values for bearing, range, D/E and SNR
   m. Other items may become necessary as the analysis proceeds.
4. The data in the CDB also includes the following information:
   a. Time-tagged contact and Ownship truth position (presented in both range/bearing and Lat/Long) as defined by the operating range measurements, or in the case of Open Ocean, the values used for exercise reconstruction.
   b. Time-tagged truth and measured Ownship depth and recorded sensor X, Y, Z position (sensor X, Y, Z will be included in the tracker data so the values can be compared to provide insight into the status of Off-Set entry status).
   c. Time-tagged contact and Ownship direction and velocity components (presented in both Water and Ground Reference).

d. Current SVP for the operating area. Included in this item will be any recorded value depicting the system selected LSS or designated as External Sound Speed (ESS) for AN/BSY-2 based systems.
e. Other environmental conditions including salinity, bottom depth, background noise, Ownship radiated noise levels, and type and characteristics (energy characteristics and location installed on contact) of any noise augmentation.
f. A Lat/Long Operational Area Grid layout for each run
g. A Historical Bottom Contour map for the Operational Area cover by each run
h. Calculated D/E truth and pertinent sound path data associated with both truth and measured D/E.

The above list presents only the key items and does not reflect the CDB content in total.

3.1.5.2 CDB Conceptual Structure

This section addresses the database implementation in a conceptual view only. Figure 6 provides an overview of that concept. All data contained in the CDB is accessible using a top down menu originating with the exercise. Each exercise which has data runs housed in the CDB is accessible and once selected, a menu providing access to data content levels ranging from the entire exercise down to a specific file(s) within a designated run or run modification (run data altered correct error or obtain compatibility). Additionally, applicable presentation types and query tools are automated and tailored to the level content and made user-friendly selectable when working in that tier of data. Some key capabilities included in the data access package are:

- Complete list of exercises and associated runs
- Top down menu selection of data presentations at levels from exercise/hull to individual tracker or combinations of trackers
- Key high level statistic associated with the runs listed (range of SNR, range, relative bearing, etc. values)
- High level charts/graphics, including target/Ownship XY charting for each run
- A variety of analysis-assisting charts and graphs accentuated by defined Sweet Spot criteria
- Ability to merge chart and graphs content and to enhance interactive analysis
- Calculated statics associated with the presented data segments (Value Variance/Standard Deviation, samples outside of accuracy threshold, same averaging interval to maximize data quality, etc.)
- User friendly capability to alter the Sweet Spot criteria and apply them to selected data sets
- Ability to create and list modified data files (all versions are retained and selectable) that reflected need data content changes; i.e., non-measurement error corrections
- Production of TMA assessment output files using the top down menu (General Dynamics Information Technology Lab and NUWC)
- Composite statics including the computation of Sweet Spot Prediction Probability based upon selected Sweet Spot criteria and qualifying data segments

- Imbedded Sweet Spot interactive contributors model to create and define the complex dynamics of Sweet Spot (process goal, but limited creation expected for the initial analysis phase)

The above items are desired key known characteristics, but the data structure and database architecture are designed to allow efficient modification and additions to these capabilities.

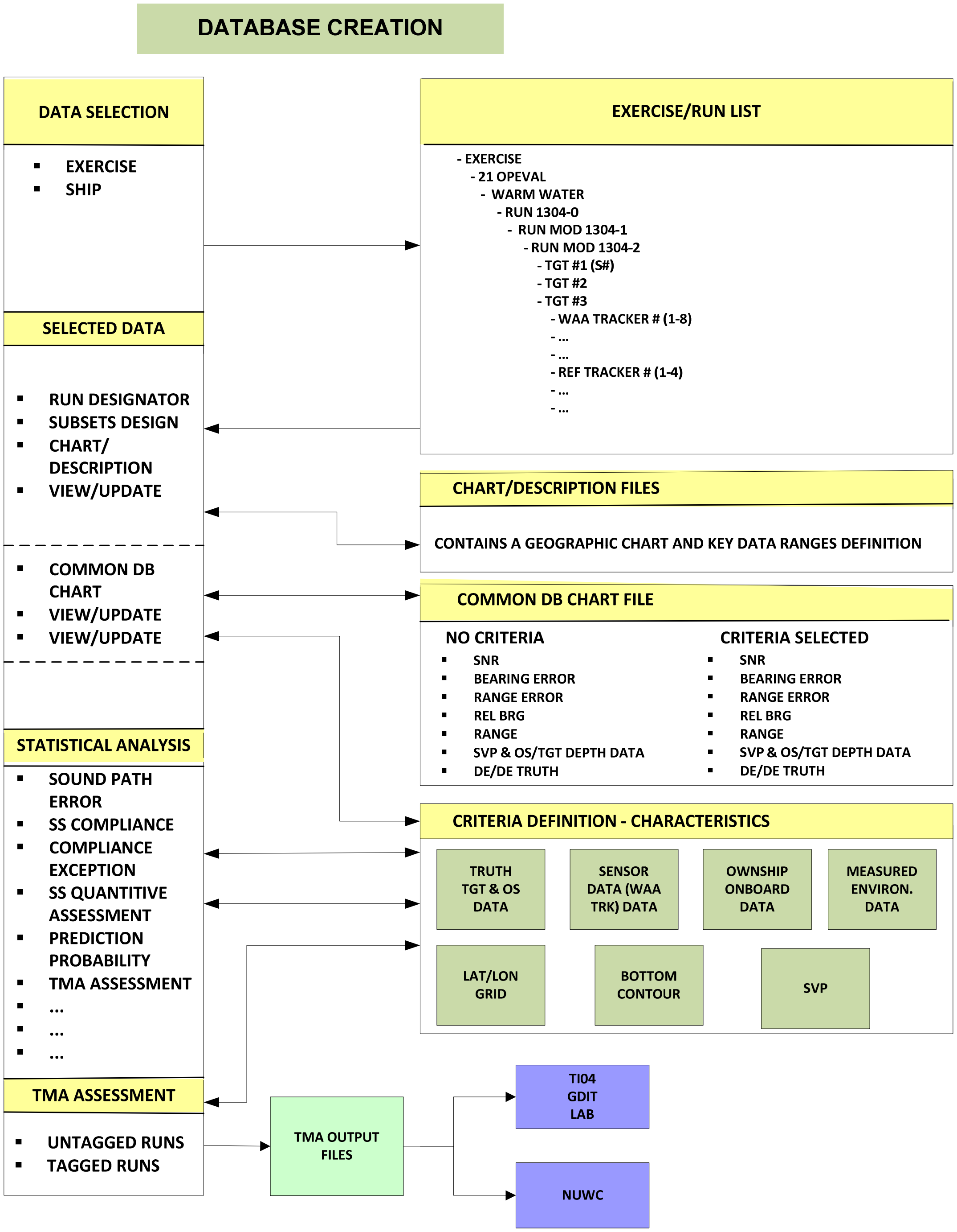

Figure 6. CDB Conceptual Structure

The CDB accommodates most if not all data elements that relate to onboard recorded Ownship Navigation, Sensor Data, Target and Ownship Truth data, which are the minimum requirement to accommodate WAA Sweet Spot analysis. This relational database architecture has been defined to have four major levels:

1. Events: Described as the top level test or exercise performed (i.e., 776 WSAT and uses UTC time reference for Start and Stop times of the exercise).
2. Runs: Described as specific maneuvers within an event (i.e., “Run By”, Arc Segment or a User Defined segment of a long event defined by X-Y plot maneuvers that would compliment a WAA analysis).
3. Run Sections: Described as sequentially numbered sections within a run. This was defined and developed because of graphing limitations of 3,900 seconds (1 hr 5 min) of the WAA Sweet Spot GUI, however this manifested into a means to further delineate specific time slices when narrowing down Sweet Spot intervals.
4. Contact Groups: Described as 1 to 1 matching of Target Truth, WAA Sensor, Reference Tracker (usually the Sphere) and a uniform time baseline item used to easily display any missing time elements.

The last operation of ETL (i.e., Load), is generated and performed based on available transformed data from the Raw Data extraction. The process remains consistent among varying raw data sources, however data mapping must be re-developed for each new heterogeneous raw data type. Sample append type queries, the basis for the Load step, are available in the WAASS2k3.mdb and are semi-automated with user entered parameters (as required) to catalog and create new events. Sample update queries are also provided which would manipulate CDB data into their desired Runs and subsequent Run Sections and Contact Group definitions.

Once this is accomplished, preliminary outputs are provided to the Analysis group to determine the following:

1. XY Plots using a team-developed graphical tool. This provides a visual of Ownship vs. Target maneuvers.
2. Valid WAA Trackers, their associated Reference tracker, number of targets and Contact Groupings. This may be an iterative process and the WAA Sweet Spot GUI allows for temporary exclusion of trackers to aid in this activity.
3. If and how many run sections need to be created. Based on if a Run is > 3,900 sec. in duration.

Through this iterative process, Contact Group definitions are the final product and they are used to begin more rigorous Sweet Spot analysis.

The following are outputs from the WAA Sweet Spot database.

Charts:

1. True Bearing, Relative Bearing, D/E, SNR and Range
   a. Non-Filtered
      1) All included targets and trackers with no Sweet Spot initial criteria applied

2) Used for determination of Contact Groupings

b. Filtered

1) The initial data points that conform to the Sweet Spot Initial Criteria are shown
2) SNR > -12, Rel Bng >15 deg broadside, Range between .3 and 30 Kyds, and D/E between –45 and 20 deg.

c. Each chart type can be viewed by Run, by Run Section or by Contact Group

d. Special charts have been developed that show Filtered and Non-filtered side by side to facilitate comparisons.

1) These charts have timeline scaling by use of interactive sliders and are to be enhanced to automatically generate new run sections per contact group as the analysis group zeros in on potential Sweet Spot time sections.

The following items define additional outputs created and formatted by the CDB:

- Unique parameters including Latitude, Longitude, Ownship/Target Depth, Tracker Measured D/E and Truth Target range and bearing are provided to the Sound Path Evaluation Tool.
- XY plots are generated by first exporting data files in the required format for the team-developed tool. The capability is a simple selection from the WAA Sweet Spot DB main menu bar.
- Tactical Control System (TCS) export files are generated via a main menu selection and parameterized to select an entire event or a specific event/run combination. This is an automated process which generates the TCS input files in the Automated Identification System (AIS) defined file formats. A Sweet Spot flag field has been designed into this export, which is used to identify Sweet Spot qualified data by the TMA algorithms. Degrees of Sweet Spot data (1=Low Sweet, 2=Mid Sweet, 3=High Sweet) has been discussed vs. a Boolean value of Sweet or Non-Sweet and will be applied for future analysis. NUWC DB format export is intrinsically defined within the Sweet Spot CDB since the NUWC DB data elements are a subset of the Sweet Spot CDB. This is a simple set of select queries that only retrieve NUWC DB data elements and insert them into the Functional_Analysis DB as a new event with description Sweet Spot Modified plus the rest of the original event description.

3.2 Sweet Spot Analysis Process

The Sweet Spot analysis process begins with the data review and definition of non-measurement error conditions. Figure 7 presents the basic process for performing those actions. Accentually, a bias condition indicates a probable non-measurement error cause. The known possible contributors have unique predictable error characteristics over a variety of operational conditions and can thus be isolated given the appropriate data set content. Once the error cause is identified, the data in most cases can be adjusted to extract the presented error. The process is greatly complicated when more than one error contributor exists; however, procedures are being developed to accommodate at least some of these instances. When the error cause cannot be defined, or adjustment is not possible, the data will be properly tagged. All results from this process are turned over to the Data Collection Process for insertion into the CDB.

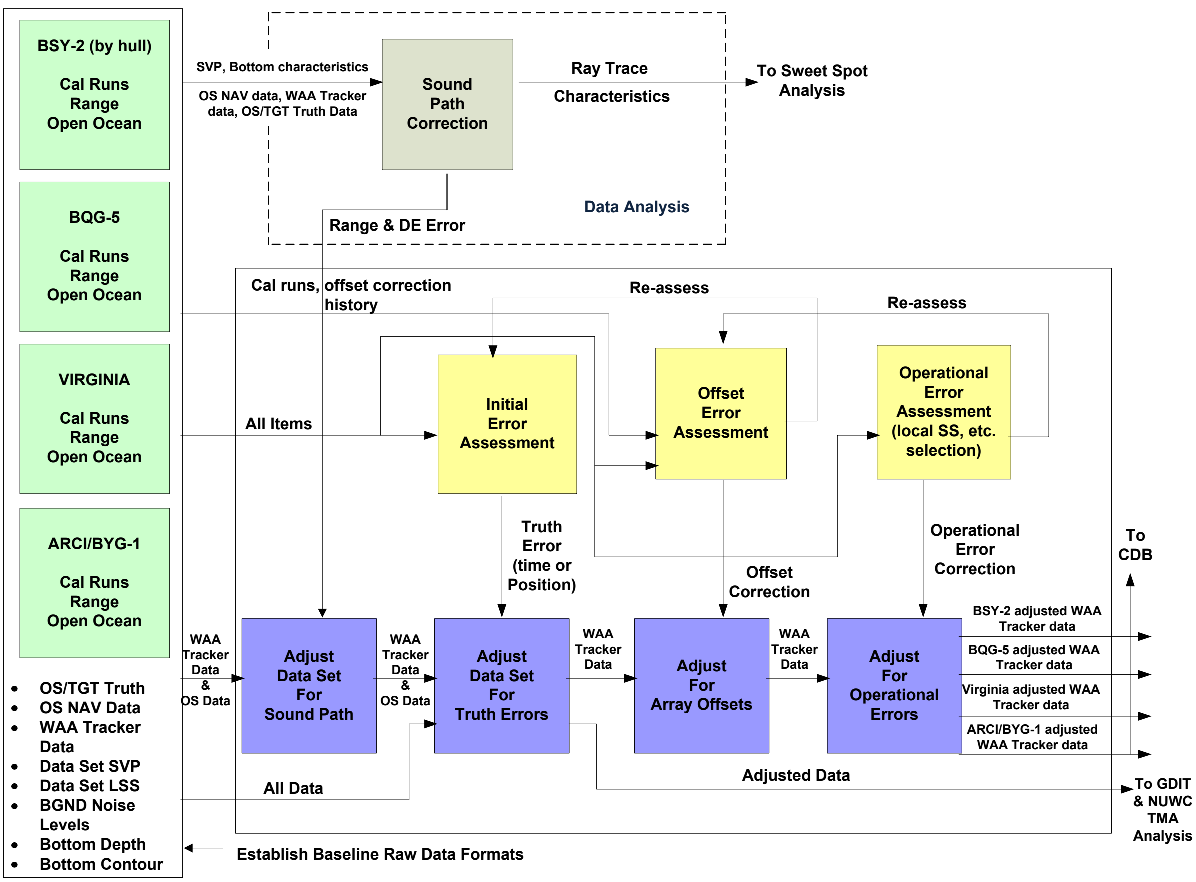

Figure 7. Non-Measurement Error Adjustment Process

3.2.1 Non-Measurement Error Reduction

Figure 7 shows the process flow for all data installed into the CDB (completed Data Collection input processing). The non-measurement errors generally fall into one of three categories:

- Hull Related - Likely to persist in all data recorded from that hull (Array Offsets, etc.)
- System Design Related – Known-design induced error conditions (straight line Slant Range vice Sound Path)
- Recording/Operator Related – Errors induced by data recording techniques or system operator error (incorrect Ownship/TGT position, established truth and recorded data time difference, incorrect operator entered LSS or SVP, etc.)

The process first looked at the first two possibilities and utilized known conditions for both to attempt to eliminate any adverse contributions created by their presents. First, the WAA Array Offset status was established using the WAA Calibration history, if available. Next, the WAA Calibration runs within the data set were evaluated to validate those findings or attempt to define the offset effects resulting from the WAA Calibration deficiencies. Once the array offset status has been resolved, the pre-calculated Sound Path parameters (during Data Collection Process) were used to assess and adjust the WFC range to remove related induced errors. From this base any residual bias-oriented error was likely caused by one of the recorded/operator sources. Each has a unique set of general characteristics:

- WAA Applied LSS - Minimum error directly off the beam which increases relative bearing moves in either direction from the beam
- Recorded Position - Whether Ownship or target, the error is predictable and adjustable using starting XY position data for the offending unit. The problem becomes more difficult, but still possible, when a position error exists for both Ownship and target
- Truth/Recorded Time - All recorded data items indicate a lag or advance of truth

3.2.1.1 Key Non-Measurement Error Considerations

Listed below are some key considerations applied during the performance of the non-measurement error identification and adjustment actions:

- Develop methods and criteria to recognize potential non-measurement errors and calculate the related adjustment values. There are bias characteristics that will be recognizable and which will signify which adjustments will need to be made. These characteristics will be defined, documented and, when possible, automated so that the analysis can readily conclude which data adjustment applies.
- Separate data sets (exercise runs) into one of the three following groups of research quality: (1) Calibration or Sensor Accuracy runs; (2) On Range Free Play or Weapon Firing Runs, and (3) Open Ocean Runs.
- Starting with the Calibration and Sensor Accuracy Runs, interrogate each run, to determine the existence of bias conditions between tracker and true range and bearing.
- Because of the high SNR conditions of these runs, they will likely be of minimal value for Sweet Spot definition but will provide the perfect data set for fixed adjustments, such as array offsets.

- As all possible data adjustments are completed, assignment of a data set quality indicator along with other header information and storage of the modified data set into the database will precede notification of the Sweet Spot Analysis and TMA Solution Quality Assessment Groups of new data availability.
- Apply applicable hull-related fixed adjustments derived from the Calibration and Sensor Accuracy Run analysis to the On Range Free Play or Weapon Firing and Open Ocean Runs.
- Analyze all On Range Free Play or Weapon Firing and Open Ocean Runs to define further adjustment requirements and use the appropriate tool to adjust the data accordingly.

3.2.1.2 Error Analysis Process Description

The following paragraphs describe a possible end-to-end error analysis procedure that could be conducted with all WAA tracker data runs. **All figures referred to in this section are contained in Appendix C.** This particular example was performed outside the Sweet Spot Database, using several tools such as Excel, Visual Basic and MATLAB. While this is not the normal procedure, it is done to illustrate the process before the full Database capability was available. This full capability will be able to perform all the analysis functions described below, and considerably more than that.

A couple of original OPEVAL test runs were analyzed in detail to see how the effort would proceed for all the other runs. A run that contained a rather large non-measurement error (reconstruction error) was chosen to illustrate the point.

Figure 1 illustrates all WAA and Spherical Array (SB) trackers as originally recorded by the on-board data collection system. The first step was to eliminate all trackers for which there is no range Truth data available, and limit the time period of interest. This process resulted in a considerable reduction of data as depicted in Figure 2. A bearing window of 20 degrees around the Truth was selected for this first step in the analysis.

An approximately 20 minute run was selected as illustrated in Figure 2. As can be seen in the figure, there is a large bearing discrepancy between the WAA tracker and the reported "truth". When available, we always try to use another non-WAA tracker for comparison with the WAA tracker. A spherical array tracker is usually chosen for this purpose, considered as a "reference tracker," because it is the closest in general characteristics (such as mode of operation, bandwidth, etc.) when compared to WAA trackers. The figure clearly illustrates that there is very good agreement between the WAA (WR01) and spherical array (SB02) trackers, indicating that they are certainly tracking the same target, except for the first and last few minutes where the SB02 tracker is not tracking properly. It can, therefore, be concluded that there is a non-WAA measurement error present in this run due to various possible conditions as outlined below.

Both trackers exhibit a large error when compared to the Truth. Figure 3 illustrates this error for the WAA tracker, which reaches a peak value of approximately 18 degrees about two thirds of the way into this run. This is certainly a huge error that must be corrected prior to proceeding with the analysis.

The first anomaly that can be noted in the original figures is that there appears to be a significant time discrepancy between the Truth and the two trackers. Examining the peak values for both traces in Figure 2 (truth peaks at 12:25:30 and the WAA tracker at 12:26:12), it was established that the time discrepancy is approximately 42 seconds, with the trackers lagging behind the Truth. This error was then corrected as depicted in Figure 4, but this still does not solve the whole problem. When this figure is carefully examined, it can be noted that the resulting bearing error appears to be a function of true bearing. The nature of this error is not fully understood at this time, but it can be tentatively corrected by applying a simple linear correction function of the form Corrected_Bng = a + b * Bng. Figures 5 and 6 illustrate this result for the WAA tracker, indicating that the bearing error has been essentially eliminated. A more sophisticated correction function could be used to further reduce the bearing error.

It should be noted that the above bearing error correction does not directly affect the resulting WAA tracker range accuracy. Only the time misalignment of 42 seconds is significant in considering the range issues in further analysis.

Figure 7 illustrates the true range and the WAA range for the time period of interest. An initial assessment of the range tracking quality indicates that the first half of the run is reasonably good, but the second half is certainly not nearly as good. We will explain in the next several paragraphs some possible reasons for this significantly large error in measured WAA tracker range. Figure 8 shows the actual range error based on the measured and true ranges. Both of these figures have not yet been corrected for the above mentioned 42 second time discrepancy.

Figures 9 and 10 correct for the time misalignment. As can be seen in those figures, there is a small improvement in measured range accuracy, but certainly not a significant amount. Other factors are at play here that affect range accuracy.

Due to the general nature of WAA track processing, there are some relative angle fans that have poor range performance. To take this factor into account, we must look at target relative bearing, as was done and is shown in Figure 11. In general, as the tracker gets closer to forward and aft end fire regions, its performance will decrease. This is certainly not an abrupt performance decrease, as it happens gradually. Figure 12 illustrates the resulting range errors when poor relative performance bearing areas have been removed from analysis. As can be observed in this figure, the first half of the run is still much better than the second half. It should be noted that the two halves of the run represent the two sides of the ship, starboard and port respectively.

Figure 13 depicts the percent error in measured WAA ranges. A straight line approximation through the first half of the run results in approximately +4 percent to -4 percent. This is a reasonably good performance for the tracker under those conditions. The second half of the run does not show any beneficial data.

Some possible reasons for this observed performance are as follows. It is known that no acoustic WAA calibration was performed on this ship. Lack of better results during the first half of the run is fairly consistent with this concept, where that range accuracy (or range error) is a function of relative bearing. Calibrating the starboard side would most likely result in improved range performance on that side. The port side of the ship has other problems. Lack of acoustic calibration is certainly one of them, but we also have a significant decrease in tracker SNR (not illustrated in this analysis), possibly due to acoustic propagation characteristics. As can be seen in several figures, target range is opening later in the run which may account for the loss of direct path propagation, also causing a significant decrease in SNR.

Some of the problems described in the above paragraphs are exactly the issues that we must study in considerable detail to improve how the WAA system could be better used by the Fleet.

3.2.2 Sweet Spot Definition and Refinement

The Sweet Spot Analysis Process utilizes the finalized and if needed, non-measurement error adjusted data, stored in the CDB to iteratively refine the established basic Sweet Spot definition by applying additional special case contributors and attempting to define the complex interactions which produce the final Sweet Spot as depicted in Figure 8.

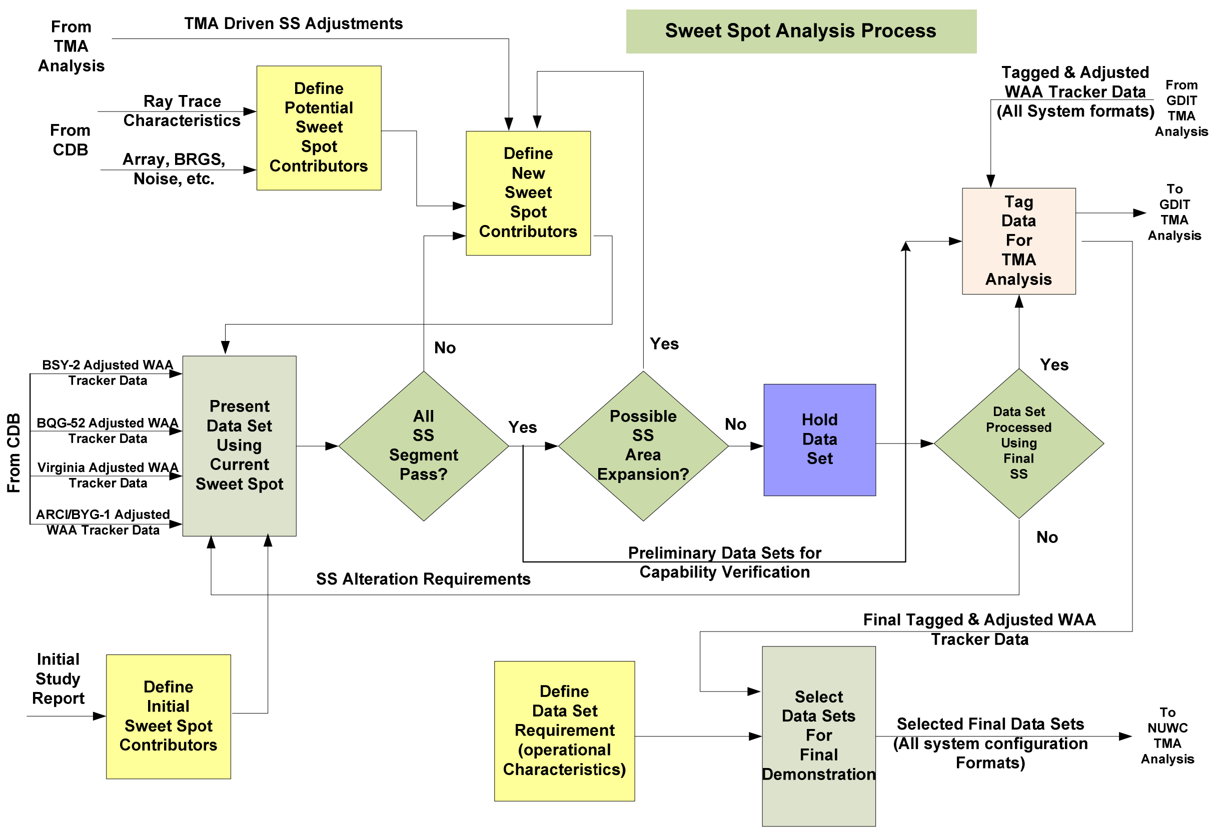

Figure 8. Sweet Spot Analysis Process

The initial findings from the FY03 NUWCDIVNPT AN/BSY-2 OPEVAL data analysis and this research effort review of the ADM, WSAT and OP/TECH EVAL reports have established that SNR, range, relative bearing and, to some extent, time in the Sweet Spot designated zone, are key contributors. In order to reestablish and further define these earlier observations, a thorough review and analysis of reports/data generated during these exercises was performed for this research effort. The primary technique applied for this analysis process was to access recorded data installed in the CDB and, using current evolving Sweet Spot characteristics, query that data to extract qualifying data segments. The boundaries and quality of each extracted data segment were evaluated and analyzed to identify causes for deviations from the established thresholds (positive or negative). The data quality and boundaries assessments were directed primarily at the WFC Ranges but also include bearing and to some degree D/E. The resulting data set analysis findings redefined the query criteria and then, once the query was adjusted accordingly, the process repeated. The data collected from each iteration was formulated to produce a statistical quality assessment and provide inputs to the Dynamic Definition Model for a thorough interactive relations prediction definition.

The methodology used in this research effort was focused upon which range of Sweet Spot parameters could be identified using data contained in reports from previous at-sea operations. Additionally, to the extent feasible, interdependencies between the parameters were also determined. This was accomplished by examining all available sea test results from various WAA configurations and submarine platforms. Results examined included AN/BSY-2 (SEAWOLF Class), AN/BQG-5 (SSN688 Class), WAA ADM (SSN688 Class), and Virginia Class sea trial events. These events provided a great deal of information from which to extract performance as a function of SNR, relative bearing and range. The review of report data derived during these exercises has confirmed probable existence of certain characteristics. At the heart of the Sweet Spot analysis we may be able to predict the combination of operational and environmental conditions that will produce a rather small dynamic spectrum where bearing accuracies of (.xx) degrees and range errors of under (x) percent can be expected. NOTE: The "xx" numbers noted below are classified (refer to Appendix D Figure 11). Although the spectrum associated with these error conditions is relatively small, a slightly larger set of error conditions of (.xx) degrees in bearing and (x) percent in range appears predictable and will produce another level of Sweet Spot around the perimeter of the Sweet Spot heart. Expansion of these initial findings is the subject of the continued analysis of additional at-sea recorded data from a variety of exercises.

3.2.2.1 Results for Range Sweet Spot:

As expected, results from various sea trials and different platform/configurations were somewhat variable. However, the basic trends across all the platforms were similar. All figures referenced in this section are contained in Appendix D. Figures 1 and 2 represent a composite range accuracy average for all the sea trial data examined. Figure 1 depicts range error vs. SNR for three different ranges for a relative bearing near broadside. Figure 2 depicts range error at 3 different ranges for the high SNR case as a function of relative bearing. It is important to note that the plotted data is representative of a WAA platform that has been calibrated to correct for any array misalignment. From the plotted data, the following initial Sweet Spot definitions are derived:

<u>Dynamic Sweet Spot Definition for WFC Ranging</u>:

Target Relative Bearing: For SNR XX and above, use broadside +/- XX degrees
For SNR XX to XX, use broadside +/- XX degrees

Target SNR: For SNR -X and above, use ranges out to XX Kyds
For SNR -X to -XX, use ranges out to XX Kyds

Target Minimum Range: XX Kyds

Target Maximum Range: Covered under Target SNR

The continuing effort focused upon enhancing the granulation of these boundaries plus incorporating other potential contributors and using a larger set of recorded data that will use these values as a baseline.

3.2.2.2 Results for Bearings Only Sweet Spot:

There are occasions when the WFC range solution is poor but the WAA tracker is still in accurate solid track. These instances occur at long ranges (wavefront has little curvature), low SNRs that are sufficient for tracking but not for WFC ranging, and other environmental conditions which preclude accurate WFC ranging. Figure 3 is a plot of WAA bearing accuracy at or near broadside as a function of SNR. Although there is some deterioration in bearing accuracy at low SNR, the bearing error, when properly tagged, can still be very useful for maintaining solutions derived from earlier received WFC data or even standalone solutions using existing bearings-only techniques altered to accept tagging. Figure 4 is provided for information and shows that the D/E tracking loop can also support tracking at low SNR levels. Figure 5 is a plot of bearing error vs. relative bearing for the high SNR case. The plot indicates increasing errors as the relative bearing nears +/- XX degrees from broadside and tagging and weighting will need to be identified independently for bearing when range tagged weight exceeds a predetermined level. From the data provided in Figures 3, 4, and 5 the following bearings only sweet spot definition is provided:

<u>Dynamic Sweet Spot Definition for Bearings Only Solution</u>:

Target Relative Bearing: Broadside +/- XX degrees

Target SNR: -XX and above

Target Minimum Range: XX Kyds

Target Maximum Range: Not applicable

These conditions alone can define the instances when Sweet Spot is probable. What has not yet been defined are first, the dynamic interactive characteristics of these key contributors, and secondly, the effects additional lesser influencing conditions. Both must be defined to establish the level of Sweet Spot probability necessary and also refine the boundaries and Sweet Spot data quality thresholds. Listed below are some of the suspected contributors being assessed:

- Bearing Rate
- Range Rate
- Ownship Speed
- Ocean Currents
- D/E Accuracy
- Multi-path Vulnerability
- Sound Path, etc.

3.2.2.3 Key Sweet Spot Definition Considerations

The process used to attempt to define the Sweet Spot was as follows:

1. The initial effort was to define a basic set of Sweet Spot parameters. The recommended items and associated values would be something similar to those defined in the earlier phases of WAA data analysis. The Sweet Spot Analysis Team, as part of their initial tasking, located any existing tools and developed the necessary modifications for calculating the sound path characteristic data for each run. If the proper tools did not exist, they were created. The path was calculated for all time segments where a WAA track existed. The data generated was later used to assess errors created by straight line processing of range data, vice sound path adjusted, plus evaluating the existence and degree of effect produced by multi-path conditions.
2. After the Calibration and Sensor Accuracy Runs were prepared (properly adjusted) by the Data Collection and Database Creation Group, all runs were passed through relational queries using the attributes used to define the Sweet Spot, and any exceptions to the declared Sweet Spot bearing and range accuracy were extracted. Working with the Data Collection/Database Creation and TMA Sweet Spot Application Groups, an explanation, and, if appropriate, resulting data adjustments (on the hull-by-hull basis) were made for these exceptions.
3. Once the calibration process defined in Step 2 was completed, the analysis of adjusted specific hull data provided by Range Free Play, Weapon Firing or Open Ocean could commence. The first step was to perform a relational query of the complete run to identify all segments meeting the attributes established for the Sweet Spot.
4. Every extracted segment was analyzed for compliance with Sweet Spot data quality thresholds and any that failed were tagged and then analyzed to determine the reason for the failure. This process should produce additional Sweet Spot parameters for consideration, and possibly outline alterations needed for existing attributes.
5. Items 3 and 4 were an iterative process with expansion produced by the addition of new run data, as it became available. Additionally, all results were forwarded to both the Data Collection/Database Creation and TMA Sweet Spot Application Group.
6. A secondary analysis was performed to identify and quantify the extent of the error produced by certain operator and environment induced conditions known to produce errors which are currently deemed insignificant. A couple of prime examples would be straight line vice sound path calculations for range, operator tendency to place D/E in manual, etc.
7. Based on information received from the TMA Sweet Spot Application Group, the Sweet Spot and surrounding area data weighting was evaluated and modified to optimize the positive effects upon updated solution generation algorithms.

3.2.2.4 Sample of a Sweet Spot Analysis using Fixed Criteria

The following steps, in conjunction with the charts in Appendix D, provide insight into the Sweet Spot analysis process and demonstrate Sweet Spot characteristics for a single data set.

1. The WAA sensor is able to process bearing and range data over a major portion of the ship's 360-degree azimuth. However, to achieve the originally specified WAA sensor performance, the target must be within much more limited azimuthal sectors that are centered around broadside relative to Ownship. Therefore, WAA sensor data processed outside those specified target azimuthal bands should be weighed much less by TMA than data collected within the specified bands if the TMA solution development accuracy is to be optimized. This strategy is not employed during TMA solution development today.
2. Although WAA sensor bearing and range measurements are generated over a wide range of target SNR, previous analysis of sea test data has found that WAA ranging accuracy substantially degrades as SNR decreases. Therefore, sensor data collected outside a minimum target SNR should be weighted much less than data collected above that SNR value during the TMA solution development if the solution range accuracy is to be optimized. Weighting of sensor SNR data is currently not employed during TMA solution development on tactical platforms.
3. WAA sensor ranging accuracy is specified within a defined range band. Many of the runs investigated as part of this study contain range data collected outside this range band. Data collected and processed by TMA outside the specified WAA sensor range band was found to be less accurate than that collected inside the range band.
4. The following provides an example of the use of fixed criteria on a given data set to extract only those range values which fall within the given criteria. The criteria used for this particular example were SNR, range, and relative bearing and were equal to the following values:
   a. SNR less than -15 dB
   b. Range between 1.5 and 12 Kyds
   c. Relative bearing 30 to 150 degrees and 210 to 330 degrees
5. Figures 6 through 10 in Appendix D provide an example of the types of information that can be extracted and analyzed from the database for a given run. Figure 6 shows the target relative bearing (truth) and the relative bearing as measured by the WAA tracker. For most of the run, the bearing is within the criteria and the WAA tracker is tracking the target very accurately. Figure 7 is a plot of the SNR during the run. The WAA SNR (in green) is within the criteria except near the end of the run. It is at this point that the WAA relative bearing is approaching the WAA baffles (bow and stern region) and this is most likely the cause of the SNR drop. Figure 8 is a plot of the tracker D/E angle and shows solid D/E track near 0 degrees indicating a direct path arrival. Figure 9 is a plot of the WAA measured range along with range truth. For most of the run, there is a 10 to 20 percent WAA range bias but the range solution is solid. The range bias is most likely caused by small array misalignment and is correctable with the insertion of calibration parameters. A calibration sea test which is required on every platform is required to determine these parameters. Near the end of the run, the WAA range solution becomes very erratic most likely due to the decreased SNR and the approach in relative bearing to the WAA baffles. In current systems, all of the WAA range values are passed to the TMA process with equal weighting.

Figures 5 through 10 demonstrate the effect of applying fixed criteria to the range solution and in this case applying a simple yes/no weighting algorithm to the solution. As can be seen from the early part of the run, the range dots are provided when the fixed criteria are met. At the end of the run when both the relative bearing and the SNR are outside the criteria, the range dots are given a weighting of zero and are therefore not plotted (and should not be provided to TMA). Since this is the area where the range solution is bad, TMA solution accuracy should be improved.

6. The above simple example demonstrates the use of the sea test database to evaluate the use of a simple set of criteria to improve the range solution quality provided to the TMA process. Future use of the database tool would include variations in the criteria such as the use of dynamic criteria associated with additional parameters such as range rate, bearing rate, D/E, etc.

3.3 TMA Sweet Spot Application Analysis

TMA is included in the Sweet Spot analysis process to demonstrate that solution improvements can result from the increased bearing and range accuracy even if they only exist for brief periods of time during a typical engagement. The initial TMA analysis focused on only multi-measurement Parameter Evaluation Plot (PEP), one of the available background solution processing capabilities (KAST/MLE) and MATE, for display and control purposes only. Realizing the ultimate Sweet Spot TMA application approach would include a scaled weighting scheme, current research resources were forced to focus on a simple YES or NO concept. The TMA Analysis Process had access to a variety of CDB stored runs previously interrogated and tagged to denote whether the data was in the Sweet Spot or not for both bearing only and bearing/range. The TMA algorithms would then either use or not use a data item accordingly. Under these conditions the amount of qualifying data in each run became a factor in evaluating the solution accuracy improvements. These factors will continue to be defined as the research effort continues. Figure 9 details the TMA analysis process.

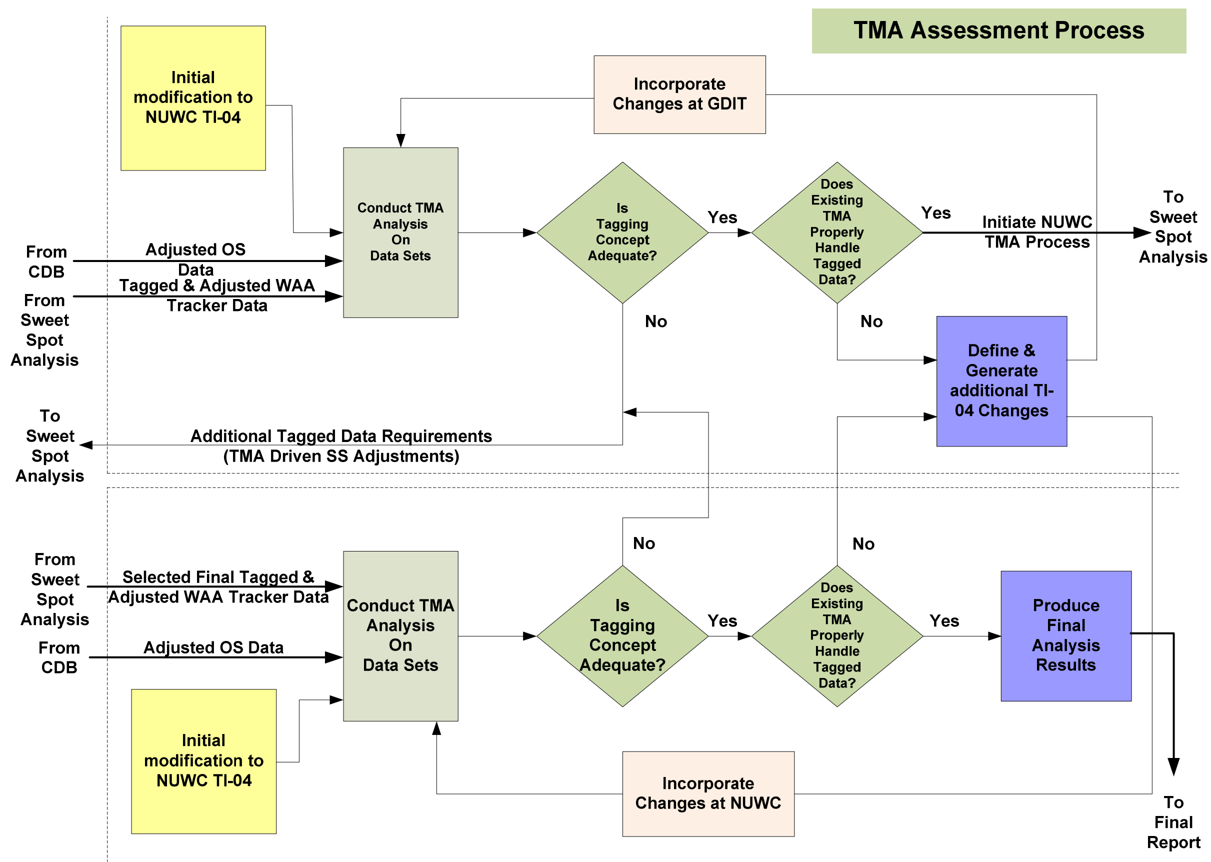

Figure 9. TMA Assessment Process

3.3.1 TMA Sweet Spot Application Key Points

The following process has been implemented to support the iterative nature of this research project. Data sets are received from the Sweet Spot Analysis team. These data sets have been properly adjusted to remove the error effects created by non-measurement errors. These data sets are also properly formatted and made available in both a tagged and untagged form. The resulting TMA output and possible local editing will produce Sweet Spot enhancement recommendations. These enhancements can then be analyzed and the cycle then repeated.

1. The first step was to define and install a stable Combat Control TMA baseline (TI04). Once installed, the baseline was thoroughly tested and all potential problem conditions including those resulting from facility limitations evaluated and, if necessary, resolved. Baseline stability was crucial in order to provide realistic comparisons for “before and after” demonstrations. It was also vital to rule out any installation contributions that could produce questionable results (positive or negative) during the Sweet Spot tagged/weighted data assessments.

2. Working in conjunction with the Data Collection team, data requirements were defined to allow recorded tracker, Ownship and other key run data to be injected into the Combat Control Subsystem. Interface specifications and associated software were developed and installed to support both General Dynamics Information Technology and NUWC TMA

capabilities. Special consideration was applied to time tag the recorded data because meaningful assessments require total synchronization of all inputs.

3. Much of the recorded data available falls under the basic categories of Calibration or Sensor Accuracy Runs. These run types would normally have minimal value due to the high SNRs associated with the run objectives. However, within these data sets there exist a variety of geometric conditions which served to validate proper insertion of run data and establish basic bearing and range solution accuracy.
4. The primary source of Sweet Spot TMA assessment data came from On-Range Free Play, Weapon Firing or Open Ocean data. The dynamic and realistic nature of these types of exercises provides true insight into the degree of improvement created by the Sweet Spot tagging. Unfortunately, the selection of these types of exercises contained in the existing database was limited. The number of geometric and environment conditions produced did not allow for a complete proof of concept; however, major trends were defined and future data requirements were established.
5. Establish characteristics already embedded within TI04 for MATE and Multi-Measure PEP solutions to allow for operator control of the data sets to be used by the applicable algorithms. Controls were developed to provide the capability to select sample averaging intervals. This capability greatly improved the assessment efficiency and accuracy. The features reduced the need for manual recording of data plus hardcopy extraction of time-tagged results.
6. Sweet Spot definition information obtained from the Sweet Spot Analysis Process assisted in the creation of additional alterations within the data filtering/averaging and internal TMA algorithm filtering/processing software and therefore maximized the effective use of the Sweet Spot weighted data. This again was an iterative process of Sweet Spot definition and Combat Control algorithm adjustment.
7. A formal event using tagged and untagged data sets could be conducted when the Sweet Spot parameters were finalized. The final TI04 algorithm adjustments were not completed to allow for the systematic recognition of Sweet Spot tagged data, and therefore, the complete process was not verified during this phase of the research project.

4.0 Summary

The focus of this first year of this research effort was on data collection, data definition and translation, database creation, the verification and refinement of previously defined WAA Sweet Spot parameters, refinement of the dynamic Sweet Spot, including additional contributions, and a demonstration of the positive effects on TMA capabilities, if possible, within the funding constraints of this effort. The importance of a well-defined and documented process for analyzing and proving the Sweet Spot criteria was crucial and we have established a process that is repeatable, predictable and can provide us with the basis for verifiable results.

This Phase I effort has developed the process of gathering and formatting at-sea collected data into a CDB, which allows further research into developing weighting factors that characterize the quality of the WAA sensor's received data at various locations within the sensor's performance envelope. The process for analyzing and developing the Sweet Spot criteria has been well-defined and is a documented process that is repeatable, predictable and can provide basis for verifiable results.

Gathering the at-sea data from TECHEVAL, OPEVAL and other evolutions for submarines with WAA required extensive assistance from outside agencies and the establishment of the mechanisms required to transport that secure data to the General Dynamics Information Technology research facility. In order to determine what portions of that data for various runs would be cogent to our analysis required a virtual bit-by-bit review of recorded data files due to the wide array of data formats from ship to ship that had to be transformed into our CDB structure. As a result of this research effort recorded data from subsequent TECHEVAL, OPEVAL and other evolutions for submarines with WAA are now standardized and installed in our CDB. While not all data is 100 percent compatible, methods have been defined to maximize the usefulness of all recorded runs.

Numerous special tools had to be developed to correct and/or supplement errors and /or shortcomings within some of the data content. These included data deficiency corrections for incomplete or missing pertinent data, Environmental Data, Sound Path Correction, and Non-Measurement Error Correction. A special tool, driven by data extracted utilizing capabilities implemented in the CDB, has been developed to assess the affects of sound path and related affects caused by deviations in D/E. Special tools and techniques have been established for defining and correcting for what are considered to be non-measurement errors which result from conditions created by the data recording process and those which become a factor because of the increased accuracy of Sweet Spot data (e.g., sound path vice straight line, installed array offsets, etc.).

A user-friendly capability to query, using a full complement of relational statements, has been designed into the CDB. This is the primary method for identifying segments of data which meet defined interim Sweet Spot criteria and provides a standardized method to review and analyze a large quantity of data runs containing a variety of operating and environmental conditions. Additionally, a vast array of flexible and Sweet Spot analysis-driven chart generation capabilities have been integrated into the CDB design with user-friendly chart manipulation capabilities, allowing the analyst to easily alter the presentation to focus on a particular area of concern. The chart generation capabilities are supported by capabilities to provide statistical quantification of data contained in the selected data segment (variance, standard deviation, average, etc.) There is an additional capability to place selected data presentations in a composite presentation, which greatly enhances analysis efforts.

The capability to perform a TMA assessment of Sweet Spot data has been installed and checked out at both the General Dynamics Information Technology Facility and at the NUWC Facility in Building 1171. While the capability to output data in a form compatible with both facilities is embedded into the CDB, the capability to properly tag all data to define each data item's Sweet Spot compliance areas was not fully implemented.

While only a preliminary analysis of selected portions of the available data were able to be performed due to Phase I resource constraints, some new contributing factors have been identified such as; D/E stability, rate of change in bearing or range, individual array SNR (FM, MA and D/E) vice established single composite array SNR, etc.

The capability now exists to perform a more detailed assessment of how Sweet Spot data can improve TMA performance with future at-sea data, and we believe that additional data from USS Virginia TECH/OPEVAL as well as from an exercise in the Pacific currently being planned to evaluate onboard acoustic sensors on USS Cheyenne, could provide the additional data needed. We believe that since the process we have developed is well defined and verified, a quick analysis could be completed to further refine the Sweet Spot criteria when this data is available.